IAS 1885

# *Proceedings* of the Indiana Academy of Science

VOLUME 114 2005 NUMBER 1

# *PROCEEDINGS* OF THE INDIANA ACADEMY OF SCIENCE

The *PROCEEDINGS* OF THE INDIANA ACADEMY OF SCIENCE is a journal dedicated to promoting scientific research and the diffusion of scientific information, to encouraging communication and cooperation among scientists, and to improving education in the sciences.

*EDITOR:* **James W. Berry**, Department of Biological Sciences, Butler University, Indianapolis, Indiana 46208. Telephone: (317)-940-9344; FAX: (317)-940-9519; e-mail: jwberry@butler.edu

*EDITORIAL BOARD:* **Hans O. Anderson** (Indiana University, Bloomington); **Robert F. Dale** (Purdue University, West Lafayette); **Rebecca Dolan** (Butler University); **Kara W. Eberly** (St. Mary's College); **Uwe J. Hansen** (Indiana State University); **Daryl R. Karns** (Hanover College); **Gene Kritsky** (College of Mt. St. Joseph); **N. Gary Lane** (Indiana University, Bloomington); **Stephen A. Perrill** (Butler University); **Paul Rothrock** (Taylor University); **Thomas P. Simon** (U.S. Fish & Wildlife Service, Bloomington); **Michael R. Tansey** (Indiana University, Bloomington); **Robert D. Waltz** (Indiana Department of Natural Resources, Indianapolis); **J. Dan Webster** (Hanover College); **Harmon Weeks** (Purdue University, West Lafayette); **John O. Whitaker, Jr.** (Indiana State University)

## THE INDIANA ACADEMY OF SCIENCE

*PRESIDENT:* Donald G. Ruch (Ball State University)
*PRESIDENT-ELECT:* Uwe J. Hansen (Indiana State University)
*TREASURER:* Edward L. Frazier (Indianapolis)
*SECRETARY:* Nils I. Johansen (University of Southern Indiana)
*EXECUTIVE DIRECTOR:* Nelson R. Shaffer (Indiana Geological Survey)
*ARCHIVIST:* Holly Oster (Indiana State Library)

*EXCHANGE ITEMS:* Items sent in exchange for the *Proceedings* and correspondence concerning exchange arrangements should be sent to the Indiana Academy of Science, John S. Wright Memorial Library, 140 North Senate Avenue, Indianapolis, Indiana 46204. Questions regarding back issues or undelivered issues should be addressed to Holly Oster at hoster@statelib.lib.in.us. Telephone (317)-232-3686.

*Cover photo:* Compass plant (*Silphium laciniatum*) in the Butler University Prairie (Indianapolis, Indiana). Compass plant leaves tend to point in ordinal directions (N-S) and were used by early settlers to show direction. Studies have shown that this orientation reduces solar heat load. Flowering stalks can reach 2.5 meters in height. Roots commonly grow 5 meters deep in the ground. Members of the sunflower family, seeds of the composite flowers are savored by birds. The Butler Prairie is a 3 acre site on campus, planted in 1987 with 50 species of native plants. Photo by Marcia Moore.

Visit the Indiana Academy of Science website at:
www.indianaacademyofscience.org

Publication date: 26 August 2005

**This paper meets the requirement of ANSI/NISO Z39.48-1992 (Permanence of Paper).**

**ISSN 0073-6767**

2005. Proceedings of the Indiana Academy of Science 114(1):1–8

# BAROMETRIC AND EARTH-TIDE INDUCED WATER-LEVEL CHANGES IN THE INGLEFIELD SANDSTONE IN SOUTHWESTERN INDIANA

**Paul C. Inkenbrandt**, **Paul K. Doss**, and **Thomas J. Pickett**: Department of Geology and Physics, The University of Southern Indiana, 8600 University Blvd., Evansville, Indiana 47712 USA

**Robert J. Brown**: Soil and Water Conservation District, 12445 Highway 41 North, Evansville, Indiana 47725 USA

**ABSTRACT.** Water-levels from a deep-shallow piezometer nest in the Inglefield sandstone depict a dynamic groundwater system. Water-levels at both the 33.5 m and 18.3 m depths fluctuate up to 0.15 m in a matter of hours. Most of this fluctuation is driven by responses to atmospheric pressure change. A strong inverse correlation exists between groundwater-levels and barometric pressure. Calculated barometric efficiency for this aquifer is 0.95, indicating a rigid aquifer skeleton. Following successful quantification and removal of the barometric effects on water-level data, the residual hydrographs suggested an additional, smaller amplitude periodicity was still present in the water-level records. These fluctuations were hypothesized to result from Earth-tide induced crustal deformation stresses. Evaluation of barometric-corrected head data by a Fast Fourier Transform method identified periodicities of water-level changes at 12.01 and 12.4 hours. These periodicities correlate well with solar and lunar tide stressors, respectively. Whereas barometric fluctuations of water-levels are driven through the well-water column and do not result from potential changes within the aquifer, Earth-tide induced fluctuations are the result of changes in aquifer potential. Further, these stress-induced changes are suggestive of a confined system, yet simple stratigraphy suggests the aquifer is unconfined. Lithologic variability within the sandstone, specifically a finer-grained and mica-rich shallow zone, likely generates confined behavior.

**Keywords:** Barometric efficiency, Earth-tides, groundwater, aquifer, Indiana

Water-level fluctuations in bedrock aquifers are essentially strain responses to stress. In large part, stress is typically a direct recharge or discharge that results in a raising or lowering of water-levels (groundwater potential), respectively. Other stresses also affect changes in potential. Measurable changes in groundwater potential on short time scales can result from seismic stresses, atmospheric pressure changes, and Earth and oceanic tides, whereas tectonic loading, basin-filling, and unroofing can change total stress on much longer scales (Furbish 1997).

Barometric pressure can change water-levels in piezometers within confined and deep unconfined aquifers. Barometric pressure directly affects water-levels in open piezometers, but loses energy in the form of heat as it exerts a force through a thick unsaturated zone, confining layers, and the aquifer (Seo 1999). The induced gradient across the well screen causes well-water fluctuations. The magnitude and rapidity of water-level change due to barometric pressure change is a function of the rigidity of the aquifer. A more rigid aquifer will react more efficiently to barometric pressure changes. Without the presence of the well, there would be no difference in potential.

Earth tidal stresses can change groundwater potential in an aquifer. As the Sun and Moon pass over a point on the Earth, gravitational forces generate a dilation of the bedrock, increasing pore space, and decreasing the potential of the groundwater in the aquifer. After the Sun and Moon pass, the gravitational force decreases, the aquifer (pore space) contracts, thus increasing the pore water potential. The more easily the aquifer deforms to gravitational stresses (less rigid), the greater the magnitude of potential change (Hsieh et al. 1987).

The objectives of our work, based upon observations of significant and short-term bedrock groundwater fluctuations, are to identify

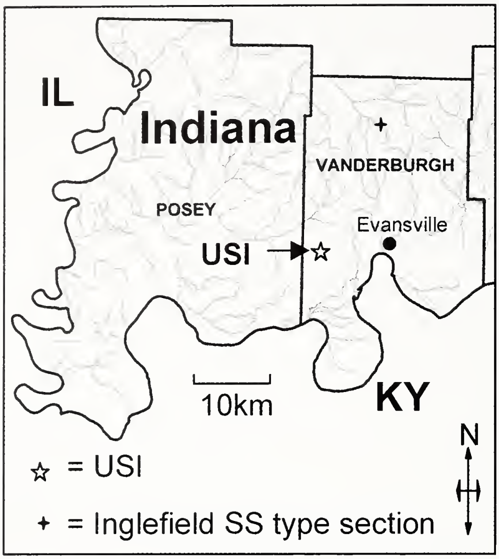


Figure 1.—A map of Posey County and Vanderburgh County in southern Indiana with the study site and type section of the Inglefield sandstone located. IL = Illinois, KY = Kentucky, and USI is the University of Southern Indiana.

the stresses, and consequent water-level changes, at work on the Pennsylvanian sandstone aquifer in southwestern Indiana. Perhaps the most important justification for this analysis is the recognition that the observed (measured) water-level fluctuations do not necessarily depict actual potential changes in the bedrock-aquifer system. Changes in the potential, or energy, of a groundwater system is generally observed by measuring water-levels in groundwater wells. However, some stresses, particularly barometric pressure changes, can generate well-water levels that do not represent actual groundwater potential. Without knowledge and quantification of these phenomena, significant error in water-level measurements may go unnoticed. Once these water-level changes are quantified, we can better evaluate and measure the true physical properties of, and potential changes in, the aquifer.

## HYDROGEOLOGIC SETTING

The type section of the Inglefield Sandstone Member of the Pennsylvanian Patoka Formation and the focus of this study are located in Vanderburgh County in Southwestern Indiana (Fig. 1). The Inglefield sandstone is dominantly a fine to medium-grained quartz sandstone that reaches maximum thickness (up to 24 m) in Vanderburgh County and Posey County (Shaver et al. 1986). Bedrock cores recovered from the University of Southern Indiana campus contain partial sequences of the Inglefield sandstone from 16–19 and 31.5–34.5 meter depths. The micritic West Franklin limestone member of the Shelburn Formation underlies the sandstone to a depth of 35.7 m, and acts as a lower confining unit. In the deep core collected at the USI campus, a short (< 0.6 m) interval of a coarse conglomeratic unit containing limestone clasts separates the limestone from the sandstone.

Although we have not been able to identify with certainty an upper confining unit locally for the Inglefield sandstone, the unit does display a pronounced fining upward character with platy muscovite grains common. Slug test results suggest a horizontal hydraulic conductivity (Kh) in the shallow aquifer (15–18.3 m depth) of 4.65 × 10-5 cm/sec (Clark et al. 2002). A laboratory permeameter analysis of a core segment from the deep aquifer (32.6 m) indicates a vertical hydraulic conductivity (Kv) of 5.3 × 10-4 cm/sec. Assuming an anisotropy (Kh/Kv) ratio of 100, an estimated Kh of the deep Inglefield (5.3 × 10-2 cm/sec) is likely three orders of magnitude greater than that of the shallow Inglefield sand, effectively generating a confined-aquifer system.

The Inglefield sandstone does serve as an aquifer locally, primarily for domestic users. Domestic and stock wells tap the Inglefield interval in the western part of Vanderburgh County where public water supply is not available. Based on the number of homes in the area that do not yet have access to the local public water supply, the total number of active domestic supply wells is approximately 100 within 5 km of the USI monitoring wells. Domestic well users discharge on the order of 1000 liters of water per day.

## METHODS

Observations and data for this research were generated in the Ground-Water Monitoring Laboratory at the University of Southern Indiana. This lab comprises a deep (WMW, 33.5 m)–shallow (EMW, 18.3 m) piezometer nest installed in the Inglefield sandstone and housed in a ground-floor laboratory of the university Science Center. Each piezometer is of 5 cm PVC construction with a 3 m screened

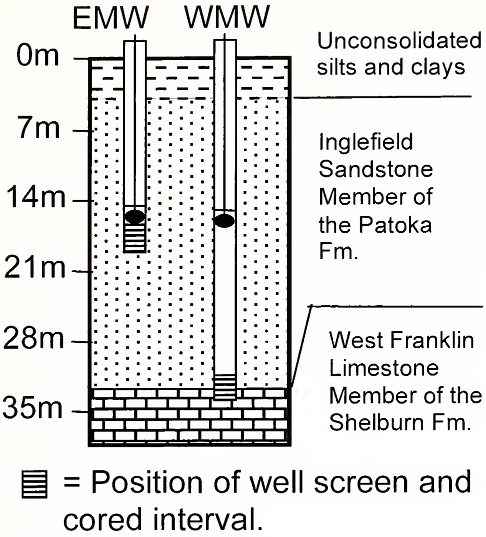

EMW
WMW
0m
7m
14m
21m
28m
35m
Unconsolidated silts and clays
Inglefield Sandstone Member of the Patoka Fm.
West Franklin Limestone Member of the Shelburn Fm.
▤ = Position of well screen and cored interval.

Figure 2.—Schematic diagram of the geologic setting and well installation for this study. EMW is the shallow monitoring well, and WMW is the deep monitoring well.

interval (Fig. 2). Water-levels were measured at hourly intervals using pressure transducers and data loggers. Hydrographs were plotted to show changes in groundwater levels over time. Barometric pressure was recorded onsite using a barometric pressure sensor and logger.

**Removing barometric influence.**—The ratio between change in water-level and change in barometric pressure describes the barometric efficiency of the well. This relationship is expressed as:

$$\omega = -(\Delta WL/\Delta BP) \qquad (1)$$

where $\omega$ = barometric efficiency, $\Delta WL$ = change in water-level (m), and $\Delta BP$ = change in barometric pressure (m).
Given a calculated barometric efficiency and the well-defined linear relationship between water-level change and atmospheric pressure change in these wells, then:

$$R(t) = W(t) + \omega[B(t) - J] \qquad (2)$$

where R(t) = residual (corrected) head (m), W(t) = well water-level (m), $\omega$ = barometric efficiency, B(t) = recorded barometric pressure (m), and J = A constant (bp at sea level, 10.3 m $H_2O$). This equation for residual (corrected) head removes barometric influence on measured groundwater-levels (Crawford & Rasmussen 1997).

**Fourier Transform evaluation.**—Corrected head hydrographs were evaluated to determine the presence of any periodicities in groundwater levels over time. Two overlapping series of 4096 hourly water-levels (170.7 days) from the deep piezometer (WMW) that had been corrected for barometric influence were evaluated using a Fast Fourier Transform. The two data sets overlap approximately three months.

The Fourier Transform reveals any oscillation frequencies that are present in a time series. The Fourier Transform is an integral transform,

$$F(\nu) = 1/\sqrt{(2\pi)} \int e^{-i\nu t}R(t)\,dt \qquad (3)$$

where $\nu$ = frequency, i = imaginary unit, R(t) = corrected head, and t = time.

In general, the Fourier Transform of real data is a complex valued function, with real and imaginary parts, so the transform of 4096 data points results in 2048 transformed points. Since the spacing of the data is one hour, the spacing in the transform is 1/4096 $h^{-1}$, and the domain of the transform is from 0–0.5 $h^{-1}$, that is, periods ranging from infinitely long down to two hours. Normally one is not interested in the real and imaginary parts separately, but rather the amplitude (Amp), or magnitude, of the transform, computed as:

$$Amp = \sqrt{\{Re^2[F(\nu)] + Im^2[F(\nu)]\}} \qquad (4)$$

where Re(F($\nu$)) and Im(F($\nu$)) are the real and imaginary parts of the Fourier Transform. Prominent frequencies have large amplitudes in the Fourier Transform spectrum. Well-defined peaks of large amplitude, and the presence of their harmonics, represent significant periodicities.

## RESULTS AND DISCUSSION

Groundwater hydrographs from both the deep and shallow piezometers suggest a dynamic groundwater system. Both deep (WMW) and shallow (EMW) water-levels fluctuate up to 0.15 m in the matter of hours. Our observations began with the initial recognition of barometric influence on measured groundwater levels (Fig. 3). Water-level hydrographs display a strong inverse correlation

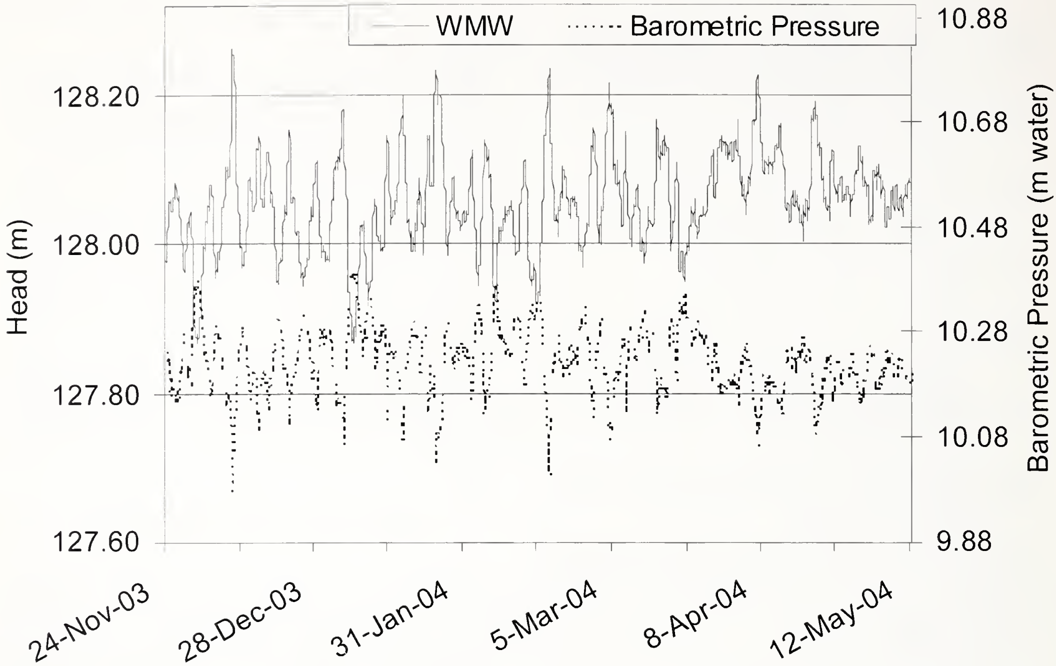


Figure 3.—Hydrograph of water levels from the deep (WMW) piezometer in the University of Southern Indiana Ground-water Monitoring Lab. Also shown is barometric pressure recorded on site. Measured water levels display a close inverse relation to barometric pressure changes.

to barometric pressure. Although both deep and shallow piezometer records clearly show this relationship, only the deep hydrograph data are used for our discussion. The inverse correlation of barometric pressure and groundwater levels is quantified by barometric efficiency (Fig. 4). The plot of head as a function of barometric pressure shows a high barometric efficiency of 0.95, indicating that during this monitoring interval, barometric pressure is a primary control of groundwater level changes.

Barometric efficiencies of confined aquifers typically range from 0.20–0.75 (Freeze & Cherry 1979). A range of $\omega$ may exist for a single aquifer because barometric pressure is not the only independent variable applying stress to the groundwater system during any monitoring interval. Because of the consistently, and atypically, high barometric efficiency observed in this study, we infer a particularly rigid skeleton for the Inglefield sandstone aquifer.

Hydrographs of corrected head are significantly different from originally recorded well-water elevation (Fig. 5). The application of Equation 2 to observed water-levels generated barometric corrections to hourly water-level data that were both positive and negative. In some cases measured water-levels were higher than actual aquifer potential, and at other times, measured water-levels were lower than the actual aquifer potential. Moreover, some of the corrections to measured levels were as large as −0.3 m and +0.1 m. Most corrections for this study were negative indicating that observed water-levels were generally higher than actual groundwater potential. This is, at least in part, due to our measured BP on site being generally lower than our selected constant value for J (sea level BP) in Equation 2.

The residual head hydrograph displays a periodicity that is not related to barometric changes (Fig. 5). The amplitude of the observed periodicity in the corrected head hydrograph is approximately an order of magnitude smaller than original water fluctuations. The large-scale influence of barometric pressure had masked these actual, small-scale fluctuations in aquifer potential. Corrected head does not have an inverse relationship with barometric pressure indicating that barometric

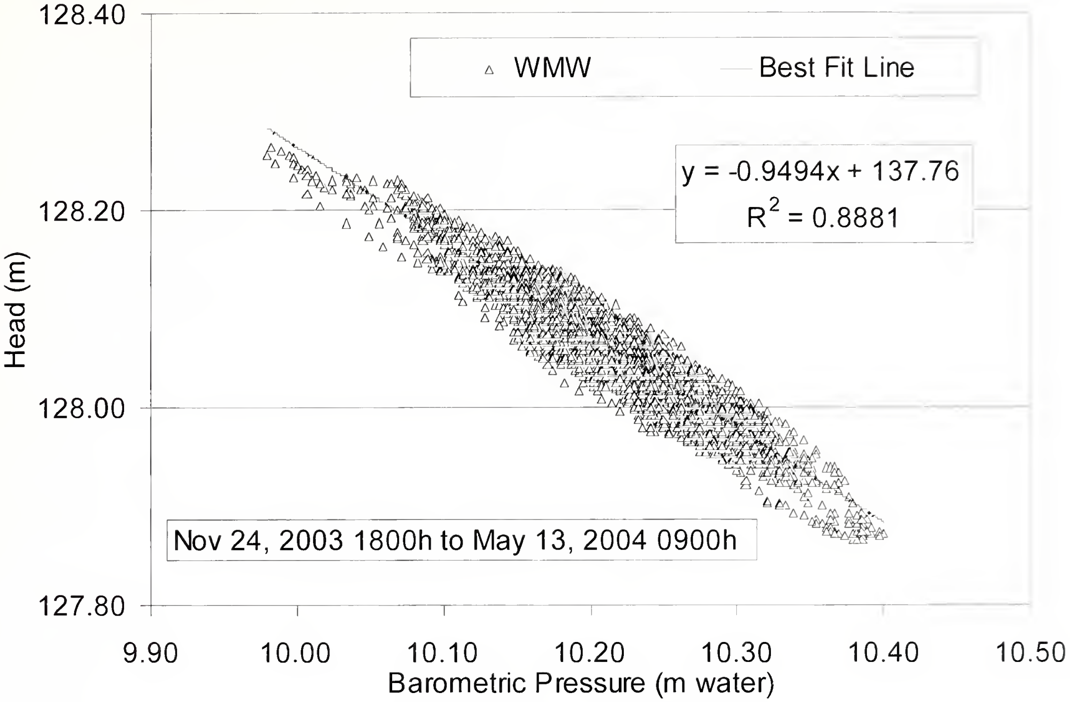


Figure 4.—Plot of ground-water levels from WMW as a function of barometric pressure for the interval shown in Fig. 3. The slope of this relationship, as characterized by the regression, represents the Barometric Efficiency ($\omega$) of the aquifer. During this monitoring interval, $\omega$ equals 0.95.

influence was successfully removed from originally measured water-levels.

Fourier transforms of the two overlapping WMW data sets show similar results. For clarity, only the transforms of the November 2003 through May 2004 corrected head data are shown here (Fig. 6). Any purely sinusoidal influence in the data will appear in the transform as a single peak with a frequency the same as that of the influence. A periodic influence that is not sinusoidal will still appear in the transform, but also with additional peaks located at multiples of the fundamental frequency; these are the (higher) harmonics of the fundamental. Our data display four distinct peaks labeled A, B, C, and D. Peak A represents a period of 24.8 h, peak B corresponds to a period of 24.0 h, peak C corresponds to a period of 12.4 hours, and D to 12.01 hours. In these data, peak D is the 2nd harmonic of peak B, which is the fundamental (1st harmonic), and peak C is the 2nd harmonic of peak A.

Peaks B and D represent a fundamental 24 h periodicity in groundwater level fluctuations and its harmonic (12 h). This influence is presumably the combined effects of solar induced Earth-tides and any anthropogenic influences that operate with a 24 h period. Anthropogenic influences might include pumping from the aquifer, recharge to the aquifer, and daily loading of the land surface above the aquifer (leading to periodic elastic compaction and dilation).

Peaks A and C are similarly related. Peak A is indicative of a fundamental 24.8 h periodicity of water-level changes, and peak C is its harmonic. Given the close match of this periodicity to the fundamental period for lunar tides, and in the absence of other known influences with this period, we infer an unequivocal signature of the lunar gravitational effect on the aquifer.

The unlabeled large amplitude, low frequency peaks near the origin of the "native" output may be related to seasonal (periodic) and other long-term changes in groundwater levels (Fig. 6). It is also difficult to discern

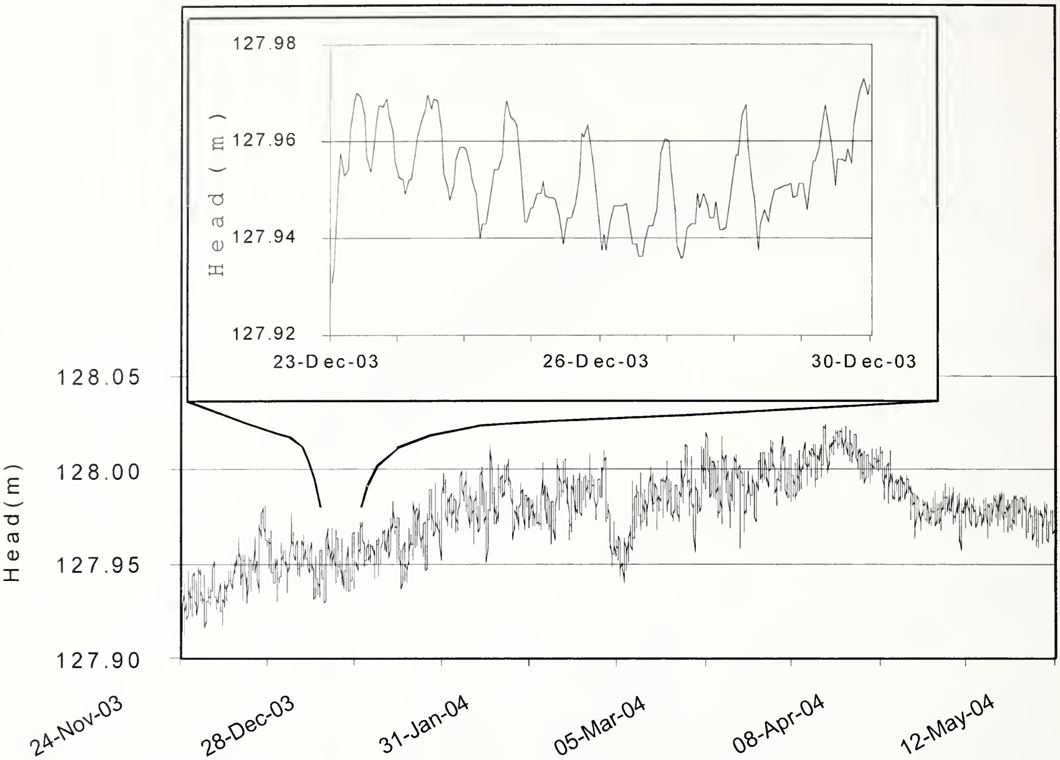


Figure 5.—Corrected head hydrograph for WMW for the period 25 November 2003 to 23 February 2004. Note the significantly smaller water level changes when compared to the observed water levels shown in Fig. 3. This hydrograph indicates that a periodicity in water-level change exists following barometric pressure correction. The inset graph is a magnification of the periodicity over a seven-day period, centered on a full moon that occurred on 27 December 2003.

real frequencies of long periodicities in these "short" data sets.

The output from the Fourier Transform of corrected head indicates that groundwater levels display periodic fluctuations over a range of frequencies. The moderately high relative amplitude (~10) of the solar and lunar tidal peaks, and the presence of harmonics, indicate that these variables have a demonstrable and measurable effect on periodic fluctuations of groundwater potential in the aquifer.

Water-levels recorded in the Inglefield bedrock piezometers display groundwater level fluctuations that result from external stresses. Specifically, the aquifer acts as a "high efficiency barometer," displaying a strong inverse correlation between water-levels and atmospheric pressure variations. Small-amplitude fluctuations were observed in the corrected head that represent tidal stresses on the bedrock aquifer. A Fast Fourier Transform identified periodicities of 12.01 and 12.4 h, corresponding well to solar and lunar tidal stresses, respectively.

Given the pronounced response of this aquifer to external stresses, we hope to use these responses as passive tests of aquifer characteristics, specifically storativity. Further, we hope to modify our monitoring to much shorter intervals in an attempt to evaluate any responses of this aquifer to seismic stress. A broadband seismograph is located on the University of Southern Indiana campus, and we have access to real-time seismic monitoring data. We regularly record New Madrid and Wabash Valley seismicity as well as larger global events at our campus instrument. Recent work by Chia et al. (2002) has suggested that some groundwater responses to seismicity vary by stress field (extension versus compression). In addition, some rapid, coseismic groundwater level changes have been inter-

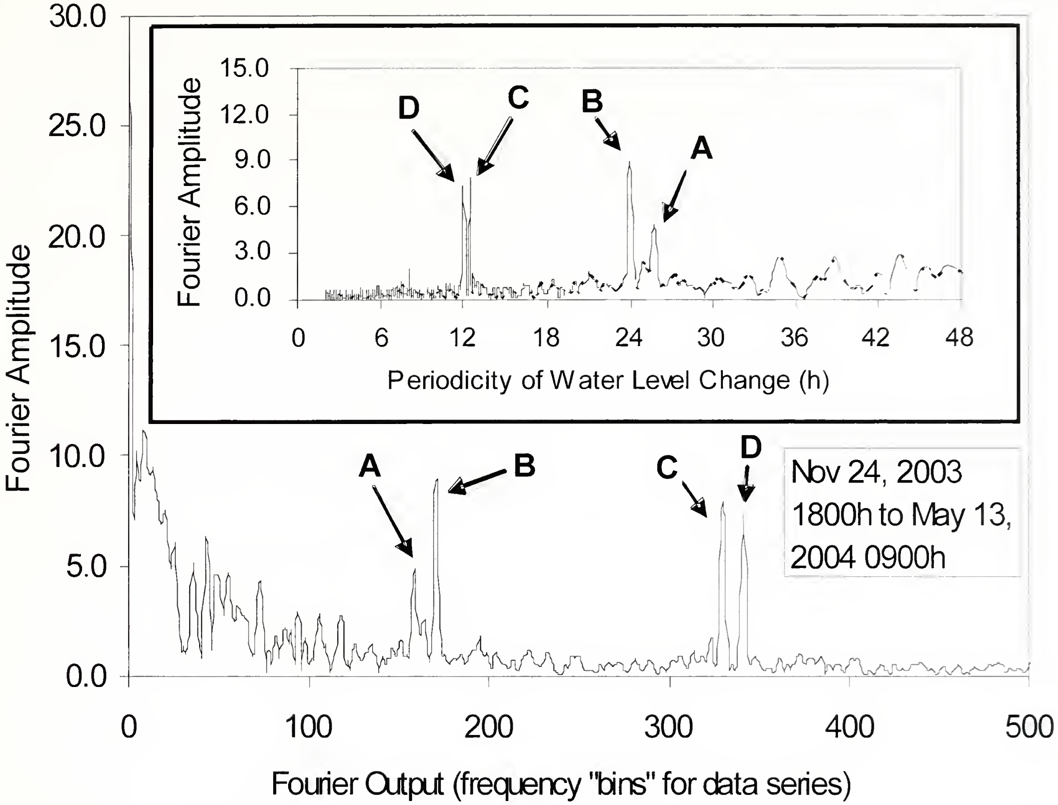


Figure 6.—Fourier Transform output for corrected head data displayed in Fig. 5. Large graph shows native output from the transform; Fourier output is defined in "Bins." For this series, (Bins/4096) = frequency of stress influence = period$^{-1}$. Inset graph shows the same data with x-axis modified to display units of periodicity in hours. Labeled peaks are discussed in the text and represent the periods of groundwater level fluctuations generated by solar (B, D) and lunar (A, C) tide stresses.

preted to alter fracture blockages at significant distances from the seismic focus (Brodsky et al. 2003).

## ACKNOWLEDGMENTS

We thank Todd Rasmussen for providing his insights into the barometric influence removal process and Bill Wilding for help with statistics. The University of Southern Indiana RISC program and Barnett Research Award provided research and travel support to Paul Inkenbrandt and Robert Brown. We also thank Henry Gray, Solomon Isiorho, and James Berry for their thoughtful and helpful reviews of this manuscript.

## LITERATURE CITED

Brodsky, E.E., E. Roeloffs, D. Woodcock, I. Gall & M. Manga. 2003. A mechanism for sustained groundwater pressure changes induced by distant earthquakes. Journal of Geophysical Research 108(B8):2390–2400.

Chia, Y.P, Y.S. Wang, C.C. Huang, J.S. Chen & H.P. Wu. 2002. Coseismic changes of groundwater level in response to the 1999 Chi-Chi earthquake. Western Pacific Earth Sciences 2(3):261–272.

Clark, S.P., M.C. Cure, T.J. Erny & P.K. Doss. 2002. New results from a deep, shallow piezometer nest in the Pennsylvanian Inglefield Sandstone Aquifer, southwestern Indiana. Geological Society of America, Abstracts with Programs 34(2):A–83.

Crawford, L.A. & T.C. Rasmussen. 1997. Identifying and removing barometric pressure effects in confined and unconfined aquifers. Groundwater 35(3):502–511.

Freeze, R.A. & J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 234 pp.

Furbish, D.J. 1997. Fluid Physics in Geology: An Introduction to Fluid Motions on Earth's Surface and Within Its Crust. Oxford University Press. New York, New York. 475 pp.

Hsieh, P.A., J.D. Bredehoeft & J.M. Farr. 1987. Determination of aquifer transmissivity from Earth tide analysis. Water Resources Research 23(10):1824–1832.

Seo, H.H. 1999. Modeling the Response of Groundwater Levels in Wells to Changes in Barometric Pressure. Ph.D. Dissertation, Iowa State University. 152 pp.

Shaver, R.H., C.H. Ault, A.N. Burger, D.D. Carr, J.B. Droste, D.L. Eggert, H.H. Gray, D. Harper, N.R. Hasenmueller, W.A. Hasenmueller, A.S. Horowitz, H.C. Hutchison, B.D. Keith, S.J. Keller, J.B. Patton, C.B. Rexroad & C.E. Weir. 1986. Compendium of Paleozoic Rock-Unit Stratigraphy in Indiana B A Revision. Indiana Department of Natural Resources, Bulletin #59, Indiana Geological Survey. 203 pp.

*Manuscript received 3 February 2005, revised 6 May 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):9–18

# AN EVALUATION OF INDIANA'S FLORISTIC QUALITY ASSESSMENT

**Paul E. Rothrock**: Department of Earth and Environmental Science, Taylor University, 236 W. Reade Avenue, Upland, Indiana 46989 USA

**Michael A. Homoya**: Division of Nature Preserves, Indiana Department of Natural Resources, 402 West Washington Street, Indianapolis, Indiana 46204 USA

**ABSTRACT.** Floristic Quality Assessment (FQA) is a valuable assessment tool for managers of natural areas, restoration ecologists, and conservationists. As a result, it has spread from initial use in the Chicago region to much of the upper midwestern U.S. The recently formulated database of coefficients of conservatism (C values) for Indiana will now permit FQA to be done statewide. This database was compared with those of neighboring states and significant differences were evident; however, these differences should only be of consequence if multiple state comparisons are being attempted. The C values for the Indiana counties included in the *Plants of the Chicago Region* are on average higher than those for Indiana as a whole. As a result, the Indiana State database should be employed for analyses that focus on state level conservation activities, as opposed to those concerned with the four state region around southern Lake Michigan. The performance of mean C ($C_{av}$) and the floristic quality index (FQI) for 28 reference sites were analyzed. In general, the guidance for interpreting these indices, laid out in Swink & Wilhlem (1994), holds. However, for at least one Natural Region of the state, namely the Central Till Plain, high quality natural areas did not score above $C_{av} = 4.1$. On the other hand, these same sites had high FQI values of 59 or higher. Both hydric and xeric reference sites attained high $C_{av}$; but the range was somewhat higher for hydric sites such as the calcareous fen or acidic seeps. Checklists with 100 or more species tolerate undersampling and may be expected to have less than 0.1 unit of fluctuation in $C_{av}$ with further sampling effort. For sites with smaller checklists, more intensive sampling is likely to result in fluctuations of ±0.2 units. An analysis of the impact of adventive species suggests that natural quality has been compromised when adventive diversity lowers $C_{av}$ by more than 0.7 units. Further evaluation of FQA for sites with moderate or marginal natural quality is still imperative for better understanding FQA metrics in Indiana.

**Keywords:** Natural area assessment, Indiana flora, mean C, floristic quality index, FQI, plant conservation

*Plants of the Chicago Region* (Swink & Wilhelm 1979) promoted many innovations in the study of regional floras. Foremost among them was the development of the Natural Areas Rating Index designed to generate objective metrics for rating the natural quality of plant communities. In the most recent edition, Swink & Wilhelm (1994) offered further refinements of the rating system and renamed the overall methodology Floristic Quality Assessment (FQA). The success of FQA is apparent in its spread from the Chicago region to a large portion of the upper midwestern U.S. The necessary species databases for performing FQA have been formulated for Illinois (Taft et al. 1997), Michigan (Herman et al. 1996), Ohio (Andreas et al. 2004), Wisconsin (Bernthal 2003), and, very recently, Indiana (Rothrock 2004). To paraphrase Swink & Wilhelm (1994), FQA allows botanists in those states an unbiased, repeatable system for (1) identifying areas of high natural value; (2) making comparisons among different sites, regardless of community type; (3) long-term monitoring of remnant natural areas; and (4) monitoring of *de novo* habitat restorations.

The philosophy and methods of FQA are fully detailed in Swink & Wilhelm (1994) as well as in the various state level FQA's reports. Briefly, however, the system depends upon the coefficient of conservatism (C) assigned to each species found in a state or regional flora. The C values, which range from zero to ten, are an estimate of the fidelity of an individual species to an undisturbed plant community that characterized the region before European settlement. For example, species of the fern genus *Osmunda* have high C values, while native but ruderal *Chenopodium* species have low C values. The C values may be used to calculate several indices of community quality—mean C ($C_{av}$) and floristic quality index (FQI). Swink & Wilhelm (1994) suggest that species inventories from sites of natural quality will attain a $C_{av}$ of 3.5 or higher. Those with high natural quality might be expected to have a $C_{av}$ of 4.5 or greater. The second metric, FQI, considers not only species quality but also species richness. Sites with natural quality attain values of 35 or higher, while those with FQI in excess of 45 are noteworthy remnants of a region's natural heritage.

Recently each species in the vascular flora of Indiana was assigned C values (Rothrock 2004). The assignment of C values was done by a team of botanists who have observed the behavior of the over 2000 species native to Indiana. The development of the species database was done independently of the floras of other states. These independent evaluations are necessary because species may have regionally adapted populations and frequently have variations in behavior due to differences in the ecological context in which the species grows. However, the fact that the species databases are independently derived in each state raises questions relating to the new Indiana database. How consistent is the assignment of C values among states? Since the *Plants of the Chicago Region* (Swink & Wilhelm 1994) includes seven Indiana counties, how distinct is that species database from the one for Indiana as a whole? Although interpretative rules for $C_{av}$ and FQI are available in the literature (Swink & Wilhelm 1994), how well do they apply to the Indiana setting? This report is the first of several that will evaluate the nature and performance of FQA in Indiana. The specific objectives are: (1) to examine the distribution of C values in the Indiana database and compare it with those of other states, (2) to compare the Indiana database with that of the Chicago region in particular, and (3) to validate $C_{av}$ and FQI metrics by applying FQA to checklist inventories available for Preserves and other reference sites.

## METHODS

Coefficients of conservatism databases were amassed from the Chicago region (Swink & Wilhelm 1994), Illinois (Taft et al. 1997), Indiana (Rothrock 2004), Michigan (Herman et al. 1996), Ohio (Andreas et al. 2004), and Wisconsin (Bernthal 2003). These were compared graphically and numerically. Species in the Indiana and state-level databases were enumerated by C value. Goodness-of-fit tests were performed to compare Indiana tallies with those of neighboring states. For each state database, C category tallies were plotted as cumulative percentage of the total flora. Because of the overlapping geographical range of C values for the Chicago region and those of the State of Indiana, more detailed numerical comparisons were made for these two databases. These comparisons include the divergence of assigned C values within each C category as well as the more general divergence regardless of C category.

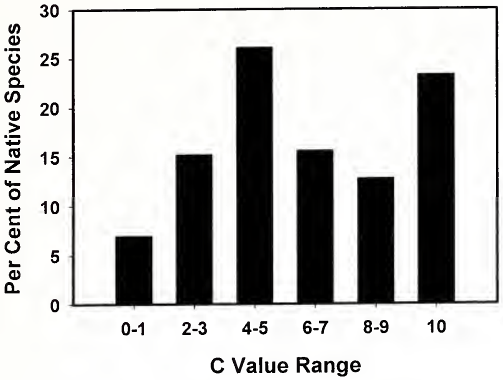
In order to calibrate the $C_{av}$ and FQI metrics for Indiana, 28 inventory checklists were gathered from the literature and unpublished data. Standard FQA was performed on these checklists using Floristic Quality Assessment Computer Program (Wilhelm & Masters 1999). Standard FQA calculates $C_{av}$ and FQI twice, the first based upon native species alone and the second based upon total species (i.e., native plus adventive). The $C_{av}$ is simply the mean of C values for species in the inventory, while FQI is: FQI = ($C_{av}$ $\surd$ number of species).

In assessing the inventory checklists it was observed that species totals varied broadly (as few as 32 and as many as 536 total species). A preliminary analysis was conducted to ascertain the potential impact that undersampling might have upon $C_{av}$. In particular, the stability of $C_{av}$ was assessed by calculating the running means for each inventory and finding by inspection the equilibrium point. Equilibrium was defined as the point where the running mean ceased varying by more than 0.2 units from the final $C_{av}$.

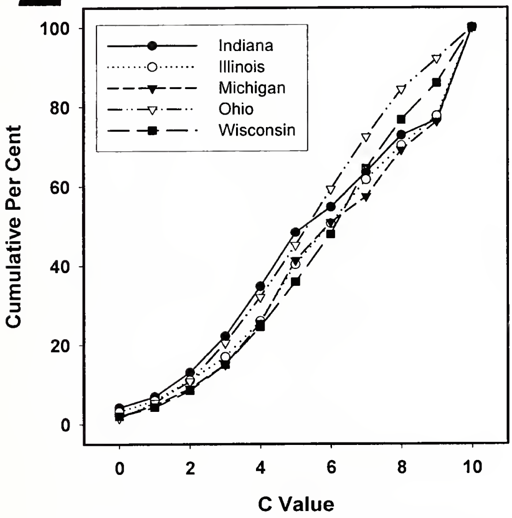
## RESULTS AND DISCUSSION

**Comparison of state databases of C values.**—The Indiana flora consists of 2017 native taxa and almost 800 adventive taxa (K. Yatskievych unpubl. data). Approximately 24% of native taxa were assigned a C = 10, the highest fidelity category (Fig. 1). These species are thought to be very sensitive to human modification of their habitat. Often they

1



2



Figures 1, 2.—Indiana C values. 1. Histogram showing the distribution of Indiana C values (native species only); 2. Comparison of Indiana C values with those of Illinois, Michigan, Ohio, and Wisconsin based upon cumulative percent.

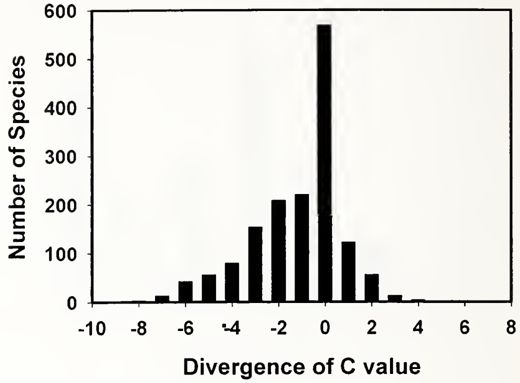
are at the extreme of their geographic range (e.g., *Cornus canadensis*), sometimes they are rare elements in the Indiana flora (e.g., *Adlumia fungosa*), or occur in specialized niches such as found in the extreme habitat of a *Sphagnum* bog (e.g., *Menyanthes trifoliata*) or the complex community structure of a remnant prairie (e.g., *Gentiana puberulenta*). A second large cohort of species was deemed to have C = 4 or 5 (Fig. 1). Species with C = 5 are understood as being tolerant of much human disturbance but the community in which they occur retains its identity as being one from pre-settlement Indiana. By contrast, C = 4 suggests that the species will occasionally thrive in an anthropogenic community type. Familiar species in this cohort include *Enemion biternatum* (C = 5) and *Anemone virginiana* (C = 4). Finally, those species assigned to C = 0 or C = 1 are the most tolerant or weedy of native species. These include *r*-selected annuals such as *Ambrosia* spp. Not surprisingly these highly tolerant species represent the smallest cohort in Fig. 1. They most often are found in disturbance sites of low species diversity and may be ecological generalists. In addition, these species are very likely to share habitat with the numerous adventive species.

For those unfamiliar with FQA it should be observed that the nearly 800 adventive species are not formally assigned a C value. The earlier Natural Areas Rating Index (Swink & Wilhelm 1979) did assign negative values to adventive species, a practice applauded by Alix & Scribailo (1998). However, an alternative approach has been adopted that allows one to assess both the natural value of a site and the somewhat separate question of how much impact adventive species are having on the site. Thus, in standard floristic analysis, as shown below (Appendix), FQA metrics are calculated twice: the first utilizes only native species, the second includes adventives species that have been assigned a default value of C = 0.

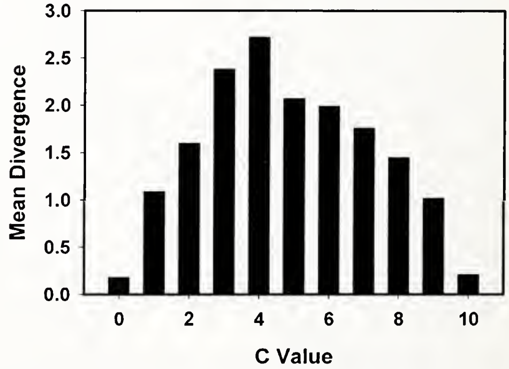
The overall distribution of Indiana taxa into cohorts of C values is broadly similar to those of neighboring states (Fig. 2). Nonetheless, all are significantly different from that of Indiana (e.g., Indiana-Illinois, $n$ = 4114, Chi Square value = 78, $P < 0.0001$). Ohio and Indiana values have a very similar proportion of species assigned C = 4 or less, but strongly diverge in the high range. This suggests that the experience of Ohio botanists led them to score relatively more taxa as C = 7 or 8 rather than 10. Conversely, Illinois and Michigan C values have their widest divergence from Indiana's in C = 3 or 4. Of the states examined, the distribution of C values for Wisconsin had the most overall difference in C values. Compared to Indiana, Wisconsin had relatively few C = 4 or 5 but a higher proportion at C = 8 and 9. Although perhaps there are biological reasons for the differences in the distribution of C values among the various states, most likely these are due to variations in human judgment between the panels of botanists tasked with assigning C values. In practice these variation should have little impact on FQA, at least within a single state. FQA is intended to provide *a priori* means of ranking natural values or a standard for year-to-year monitoring of an individual site and so only demand that each practitioner draw from a standard database of C values and that the derived metrics be calibrated for their flora.

**Comparison of Indiana and Chicago region C values.**—For seven counties in the extreme northwest portion of Indiana there are actually two sets of C values, those created for the Chicago flora and those for Indiana as a whole (Swink & Wilhelm 1994; Rothrock 2004). Analysis shows that approximately 30% of species in common between Indiana and the Chicago region were categorized into the same C cohort (Fig. 3). At the same time, the two sets of coefficients have obvious differences. More than ⅓ of Indiana species diverged from Chicago C values by 1–3 cohorts and on average Indiana C values were 1.2 cohorts lower than those of the Chicago region. According to Fig. 4, the lower C values for the Indiana database were the result of differences in ranking across most of the C scale, but the largest differences were among Indiana species assigned C values of 3 and 4 (Fig. 4) where the C values had a mean divergence of 2.4 or more. By far the least difference corresponded to those of C = 0 or C = 10 where mean divergence was less than 0.2. These results indicate that the most sensitive as well as the most tolerant species are easy to recognize and have stable ecological behavior throughout the Chicago and Indiana region. On the other hand, midrange species were, on average, assigned higher C values in the Chicago region. Rothrock (2004) hypothesized two biological reasons for this pattern. First, some of the species involved have a southern distribution from the Gulf of Mexico northward along the Mississippi Embayment into southern Indiana. These species may also have outlier, disjunct populations in dune relict communities in northwestern Indiana. The second hypothesis posits that the ability of some plant species to disperse, invade, and become established has been altered in areas with intensive agricultural and suburban/urban development as seen in parts of central and northwestern Indiana.

3



4



Figures 3, 4.—Comparison of Indiana C values with those of the Chicago region. 3. Divergence of C values on a species by species basis; 4. Mean deviation within C value cohorts.

**Calibration of mean C and FQI for Indiana.**—Given the differences between C values of the Chicago area and those of Indiana as a whole, this section examines available checklists for sites in Indiana and their performance in inventory level FQA analysis. These sites are largely ones expected to have medium or high natural values, but they also encompass several with low natural value. It is anticipated that future papers will more carefully focus upon FQA of restoration and mitigation sites and provide case studies that use transect as well as inventory data.

Among the checklists analyzed, $C_{av}$ (native species) ranged from a low of 2.7 for a seasonally-flooded basin (Taylor University campus, Grant County) to a high of 6.3 for the Lime Lake Nature Preserve (Appendix). The resulting $C_{av}$ values are coherent given the histories of these sites. The seasonally-flooded basin is strongly dominated by perennial species that can tolerate periodic mowing during the dry periods of summer. In turn, it is surrounded by broad expanses of mowed turf. By contrast, the wetland habitat included in the checklist from Lime Lake Nature Preserve has experienced minimal direct human and little change in hydrology. It retains a mosaic of marl seeps and pools, wet hummocks, and fen and lake-margin vegetation. During the past decade it has been subjected to fire management and control of exotic species.

The sites subjected to FQA (Appendix) included a wide range of community types, sizes, and wetness. The driest sites, as determined by National Wetness Categories for plant species, were the Perry County sandstone glade, Lookout Point and Wea Creek prairies, and Versailles State Park limestone glade. All of these sites had $C_{av}$ (native species) of at least 4.0 with the highest value reaching 4.9. At the opposite end of the wetness spectrum were Fox Lake and Saugany Lake and the seeps at Turkey Run State Park. Their $C_{av}$ (native species) had a somewhat higher range than that of the driest sites, ranging from 4.9 to 5.4. Nonetheless, these results indicate that habitats across the range of wetness can record a high level of ecological integrity based upon these $C_{av}$ values.

The checklists in the Appendix represent a diversity of site sizes and sampling efforts. They had as few as 32 and as many as 536 total plant species. An analysis of running $C_{av}$ values was undertaken in order to better understand the stability of $C_{av}$ among sites with varying species diversity and sampling intensities (Fig. 5). Checklists with 100 or more total species attained stable $C_{av}$ (i.e., 0.2 or less deviation from the final value) when 40-80% of species were tallied. For checklists of less than 100 species, $C_{av}$ was generally unstable until at least 75% of species were included in the running mean (Fig. 5). These results suggest that in making comparisons between sites where the inventory checklists are restricted in size, one might anticipate that variations on the order of 0.2 units merely represent noise in the data and could potentially emanate from overlooking a few species in the site tally.

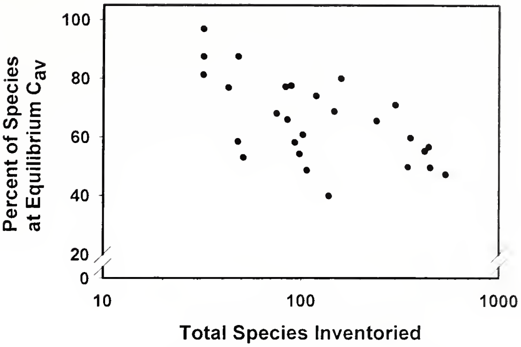


Figure 5.—Scatter plot showing the relationship between total diversity at a site and the percent of species attained when the running mean of C values reached equilibrium (i.e., running $C_{av}$ = 0.2 units of final $C_{av}$).

For this study, checklists were most available for forested natural areas in the Central Till Plain Natural Region. These include Botany Glen, Fall Creek Gorge, Fogwell Forest, Ginn Woods, Mounds State Park, and Wilbur Wright Fish and Wildlife Area (Appendix). With the exception of the special case of Mounds State Park, $C_{av}$ (native species) had a narrow range: 3.8–4.1. Because of the presence of the high quality fen at Mounds State Park, the park overall had a $C_{av}$ for native species of 4.5. On the other hand, when the analysis was more limited to the large floodplain forest and seeps within the park, $C_{av}$ was lowered to 4.0. Thus, the analyses available to date indicate that the best natural woodland sites in the Central Till Plain, whether for historical or for innate biological reasons, have a limited number of species from the highest fidelity categories. Their $C_{av}$ (native species) plateau in the low 4 range.

Some wooded preserves outside of the Central Till Plain Natural Regions may have a meaningfully higher $C_{av}$ (Appendix). The highest measured was Barker Woods from the Lake Michigan Natural Region ($C_{av}$ = 5.0) and Bendix Woods from the Grand Prairie Natural Region ($C_{av}$ = 4.7). Yellow Birch Ravine Nature Preserve from the Shawnee Hills

Natural Region ($C_{av}$ = 4.6) was also of very high quality. Barker Woods has much swampy habitat with acidic soils but also includes some well drained parallel ridges with fine sandy soil. These unusual and diverse habitats harbor species near their southern range limit including a number of state rare, threatened or endangered species. By contrast, the old-growth Bendix Woods is a rich mesic woods with many high quality but not necessarily threatened or endangered species. The high $C_{av}$ value for Yellow Birch Ravine Nature Preserve may be accounted for by the numerous microhabitats associated with bluffs and the wide range of exposures, moisture conditions, and substrate types.

According to experience in other states (Swink & Wilhelm 1994), restoration communities seldom attain $C_{av}$ (native species) of 3.5 or above. The Upland Prairie Restoration marginally agrees with this pattern. By the fifth year, the 25 acre (72 ha) site had reached a $C_{av}$ = 3.2 (Appendix) and, by the twelfth season, this value rose to $C_{av}$ = 3.7. Since no new species have been observed on the site for at least the two seasons, this site may be at or near its maximum $C_{av}$. Also, as further discussed below, the other FQA metrics (total species $C_{av}$ and FQI's) provide clear signals that this restoration site has not attained a community structure equivalent to a natural tallgrass prairie.

FQA typically entails first calculating site metrics with only native species and then with all species, native and adventive. The differences in these results can document the impact that exotic species are having upon a site. Several of the reference sites had problematic amounts of exotics and therefore allow us to examine their specific influence on $C_{av}$ results. The Upland Prairie Restoration – 5th year (Appendix) had the largest difference between the two $C_{av}$ values, 1.4 units. Since this site was converted from agricultural use to a tallgrass community, it still retained a legacy of non-native weeds, species such as *Cirsium arvense*, *Dipsacus fullonum*, and *Phalaris arundinacea*. By 12 years after planting the restoration, non-native species continued to lower $C_{av}$ values strongly—by 1.2 units. Among non-restoration sites, Wilbur Wright Fish and Wildlife Area had the highest diversity of adventives, reducing $C_{av}$ by 1.1 units. Some areas in Wilbur Wright Fish and Wildlife Area (e.g., Unit 3 and 4) were dominated by adventive species and even the most intact area (Unit 2) frequently had an exotics problem. Among high quality natural areas, four sites had a divergence of native versus total $C_{av}$ values of 0.7 units (Appendix). These include Botany Glen, Fall Creek Gorge, Ginn Woods, and Mounds State Park. Typically these sites had their diversity of adventive species concentrated on the margins of the natural areas or in successional communities that were a part of the overall property. Thus this amount of "exotics load," while of concern, may not be sufficient to detract from the preservation potential of a site.

The second standard metric derived from FQA is that of floristic quality index (FQI). This metric provides a numerical summary based upon the quality as well as the richness of species. As one might expect, it is somewhat dependent upon the size of the natural area under consideration. Inventories that focused upon tiny (i.e., less than 1 ha), high quality glades, barrens, and prairie fragments had FQI's ranging from 27–42. Clearly, in these cases FQI does not always supply meaningful insight into their natural quality. On the other hand, given their limited size, several seep communities studied by Homoya (1984) had surprisingly high FQI's of 50.7 and 53.6. Among the checklists reviewed, five sites—Botany Glen, Fall Creek Gorge, Fogwell Forest, Ginn Woods, and Wilbur Wright FWA—had a $C_{av}$ between 3.5–4.5 but also encompassed the complex of natural and successional communities found on a more commodious land area (i.e., greater than 10 ha in size). In each case their FQI for native species registered between 59–77, confirming their high natural area potential. As a contrasting condition, the Upland Prairie Restoration (in its 12th year), with its $C_{av}$ of 3.7, merely achieved an FQI of 25.1. Unfortunately, at this time, we do not have additional Indiana examples of intensively inventoried sites with moderate $C_{av}$ and FQI values. These would give us a better picture of the causes and extent of compromise of natural quality that would lead to these FQA outcomes.

## ACKNOWLEDGMENTS

We are indebted to Gerould Wilhelm (Conservation Design Forum) for his comments on an earlier draft of this report and James Robb

(Indiana Department of Environmental Management) for his work in launching and overseeing the FQA project for Indiana. Special thanks are due to Kay and George Yatskievych, Tony Reznicek, Rebecca Dolan, Bill Minton, and Eric Knox for their work in developing the database of C values for Indiana. Funding by ARN A305-4-53 EPA Wetland Program Development Grant CD975586-01 is gratefully acknowledged.

## APPENDIX

## FLORISTIC ASSESSMENT REFERENCE SITES

Each entry includes county level location, literature citation, natural region (based upon Homoya et al. 1985), available parameters (such as aerial extent or lake depth), a brief description of habitat and/or community type, and a listing of the basic FQA results for native species alone and for total species (i.e., native + adventives). $C_{av}$ = mean coefficient of conservatism; FQI = floristic quality index.

1. Barker Woods Nature Preserve, LaPorte County (Riemenschneider & Reed 1985). Lake Michigan Natural Region. 12 ha. Poorly drained, medium to strongly acidic soils; abundant tree species include *Acer rubrum* and *Quercus palustris*. Parallel ridges of fine sandy soil; abundant tree species include *Q. rubra* and *Sassafras albidum*. Native species = 146, $C_{av}$ = 5.0, FQI = 60.7; Total species = 159, $C_{av}$ = 4.6, FQI = 58.4.

2. Bendix Woods Nature Preserve, St. Joseph County (Blodgett & Riemenschneider 1983). Grand Prairie Natural Region (Kankakee Sand Section). 11 ha. Old growth mixed hardwood forest. Native species = 112, $C_{av}$ = 4.7, FQI = 49.3; Total species = 118, $C_{av}$ = 4.4, FQI = 48.1.

3. Big Oaks National Wildlife Area (Basey & Badger 2004). Bluegrass Natural Region (Flats and Canyon Section). Dry, fire-managed grasslands dominated by *Andropogon virginicus* and *Solidago juncea*. Poorly drained soils with acidic upper horizon (pH as low as 4.0). Results are a composite from three sample areas: 5, 16, and 26. Native species = 39, $C_{av}$ = 2.9, FQI = 18.1; Total species = 51, $C_{av}$ = 2.2, FQI = 15.8.

4. Botany Glen, Grant County (Stonehouse et al. 2003). Central Till Plain Natural Region (Bluffton Till Plain Section). 18 ha. Mature upland woods, ravine woods, floodplain and seep, and old field. Native species = 295, $C_{av}$ = 4.0, FQI = 68.5; Total species = 357, $C_{av}$ = 3.3, FQI = 62.3.

5. Fall Creek Gorge Nature Preserve, Warren County (Tonkovich & Sargent 1993). Central Till Plain Natural Region (Entrenched Valley Section). 60 ha. Old growth mesic woods (*Acer saccharum*, mixed *Quercus* spp., *Fagus grandifolia*, and *Carya* spp.), wet woods, cliff and ravine communities, and large old field. Native species = 288, $C_{av}$ = 3.8, FQI = 64.1; Total species = 346, $C_{av}$ = 3.1, FQI = 58.5.

6. Flint Barrens, Harrison County. Unpublished checklist. Highland Rim Natural Region (Mitchell Karst Plain Section). 24 ha. Chert barrens community in rolling sinkhole topography; dominated by *Schizachyrium scoparium* and *Sorghastrum nutans* with oak copses of mostly *Quercus stellata*. Native species = 276, $C_{av}$ = 4.0, FQI = 67.2; Total species = 289, $C_{av}$ = 3.9, FQI = 65.6.

7. Fogwell Forest Nature Preserve, Allen County (Rothrock 1997). Central Till Plain Natural Region (Bluffton Till Plain Section). 11 ha. Mature flatwoods dominated by *Acer saccharum*, *Fagus grandifolia*, *Quercus rubra*, and, near vernal pools, by *Quercus bicolor*; rich spring ephemeral flora; surrounded by housing subdivision, agricultural activity, and old fields. Native species = 210, $C_{av}$ = 4.1, FQI = 59.3; Total species = 240, $C_{av}$ = 3.6, FQI = 55.4.

8. Fox Lake, Steuben County. Unpublished checklist. Northern Lakes Region. Sample from 100 m. littoral zone along county road 200W. Includes an extensive bed of *Eleocharis* spp. Native species = 29, $C_{av}$ = 5.4, FQI = 29.2; Total species = 30, $C_{av}$ = 5.2, FQI = 28.7.

9. Ginn Woods, Delaware County (Ruch et al. 1998; Ruch et al. 2004). Central Till Plain Natural Region (Bluffton Till Plain Section). 61 ha. Old growth *Acer saccharum–Fagus grandifolia* forest with vernal pools and tree gap meadows; also includes a marshy area and woods-old field ecotone. Native species = 364, $C_{av}$ = 3.9, FQI = 74.1; Total species = 441, $C_{av}$ = 3.2, FQI = 67.3.

10. Hemlock Bluff Nature Preserve, Jackson County (Gray & Bacone 1979). Highland Rim Natural Region (Brown County Hills Section). 16 ha. Dry-mesic upland forest, bluff and ravine forest, floodplain forest; contains relictual *Tsuga canadensis*. Native species = 259, $C_{av}$ = 4.0, FQI = 64.9; Total species = 299, $C_{av}$ = 3.5, FQI = 60.4.

11. Lime Lake Nature Preserve, Steuben County. Unpublished checklist of fen, marl flats, and lake shore from the portion of the preserve lying south of I-80/90. Northern Lakes Natural Region. 20 ha. Wetland mosaic dominated by graminoids such as *Carex stricta*, *C. sterilis*, *Eleocharis rostellata*, and

*Schoenoplectus acutus* and *S. pungens* with a diverse mix of calciphilic forbs. Native species = 71, $C_{av}$ = 6.3, FQI = 53.4; Total species = 75, $C_{av}$ = 6.0, FQI = 52.0.

12. Lookout Point Gravel Hill Prairie, Tippecanoe County (Post et al. 1985). Central Till Plain Natural Region (Entrenched Valley Section). Less than 1 ha. Mid-grass prairie; the common species include the grasses *Bouteloua curtipendula*, *Schizachyrium scoparium*, and *Hesperostipa spartea* and forbs such as *Amorpha canescens*, *Symphyotrichum oblongifolium*, *Dalea purpureum*, *Erysimium capitatum*, and *Brickellia eupatorioides*. Native species = 74, $C_{av}$ = 4.9, FQI = 41.7; Total species = 84, $C_{av}$ = 4.3, FQI = 39.2.

13a. Mounds State Park, Madison County, Indiana (Rothrock et al. 1993). Central Till Plain Natural Region (Tipton Till Plain Section). 105 ha. Floodplain forest with seeps; wooded slopes and some bluffs; fen; upland woods; cultural areas with some old fields. Native species = 380, $C_{av}$ = 4.5, FQI = 87.3; Total species = 448, $C_{av}$ = 3.8, FQI = 80.4.

13b. Mounds State Park - fen. 2 ha. Actively managed by Division of Nature Preserves; low per cent cover of *Rhamnus frangula*. Native species = 96, $C_{av}$ = 5.9, FQI = 58.0; Total species = 97, $C_{av}$ = 5.9, FQI = 57.7.

13c. Mounds State Park - floodplain forest and seeps. Contains some residual *Maclura pomifera*, early stage infestation by *Alliaria petiolata*, and a major park trail and boat ramp. Native species = 130, $C_{av}$ = 4.0, FQI = 45.2; Total species = 146, $C_{av}$ = 3.5, FQI = 42.6.

14. Perry County Limestone Glade (Bacone et al. 1983). Shawnee Hills Natural Region (Crawford Upland Section). Less than 1 ha. Dominant herbaceous vegetation of *Sorghastrum nutans*, *Andropogon gerardii*, and *Schizachyrium scoparius*; diversity of forbs such as *Eryngium yuccifolium*, *Helianthus mollis*, *Gentiana quinquefolia*, and *Liatris aspera*. Native species = 47, $C_{av}$ = 5.2, FQI = 35.7; Total species = 47, $C_{av}$ = 5.2, FQI = 35.7.

15. Perry County Sandstone Glade (Bacone et al. 1983). Shawnee Hills Natural Region (Crawford Upland Section). Less than 1 ha. - long narrow strip at the top of a high cliff; trees include stunted *Juniperus virginiana*, *Quercus stellata* and *Q. marilandica*; shrubs include three *Vaccinium* spp. and *Kalmia latifolia*. Native species = 32, $C_{av}$ = 4.8, FQI = 27.2; Total species = 32, $C_{av}$ = 4.8, FQI = 27.2.

16. Plaster Creek Seep Springs, Martin County (Homoya 1984). Shawnee Hills Natural Region (Crawford Upland Section). Less than 1 ha.; pH 5.6–5.9. The dominant ferns *Osmunda cinnamomea* and *O. regalis* form hummocks; woody shrubs include *Ilex verticillata*, *Photina melanocarpa*, *Lindera benzoin*, and *Viburnum dentatum*; scattered *Sphagnum*. Native species = 107, $C_{av}$ = 5.2, FQI = 53.6; Total species = 107, $C_{av}$ = 5.2, FQI = 53.6.

17. Saugany Lake, LaPorte County (Alix & Scribailo 1998). Northwestern Morainal Natural Region (Valpariso Moraine Section). 30 ha.; maximum depth 19.9 m. Spring-fed and almost completely surrounded by homes but rated as Class One (least eutrophic) by Indiana Department of Environmental Management; limited emergent zone. Native species = 43, $C_{av}$ = 4.9, FQI = 31.9; Total species = 47, $C_{av}$ = 4.4, FQI = 30.5.

18. Seasonally flooded basin and adjacent pond margin, Taylor University campus, Grant County. Central Till Plain Natural Region (Bluffton Till Plain Section). Unpublished checklist of east end of Taylor Lake and an adjacent marsh. 2 ha. Over the past three decades the marsh often has portions mowed during dry summer periods. Dominant species include *Typha* spp., *Hordeum jubatum*, *Juncus articulatus*, and *Agrostis gigantea*. Native species = 27, $C_{av}$ = 2.7, FQI = 14.2; Total species = 36, $C_{av}$ = 2.1, FQI = 12.3.

19a. Turkey Run State Park - seep area 1, Parke County (Ebinger & Bacone 1981). Central Till Plain Natural Region (Entrenched Valley Section). Less than 1 ha. Cool, slight alkaline seep dominated by *Carex sterilis*, *Selaginella apoda*, *Bidens aristosa*, and *C. leptalea*. Native species = 30, $C_{av}$ = 5.4, FQI = 29.8; Total species = 32, $C_{av}$ = 5.1, FQI = 28.8.

19b. Turkey Run State Park - seep area 2. Less than 1 ha. Three zones: zone 1 dominated by *Carex sterilis*, *Eleocharis erythropoda*; zone 2 by *Impatiens capensis* and *Rorripa nasturtium-aquaticum*; zone 3 by *Acorus calamus*. Native species = 40, $C_{av}$ = 5.1, FQI = 32.1; Total species = 43, $C_{av}$ = 4.7, FQI = 31.0.

20. Twin Swamp Nature Preserve, Posey County (Mark & Gordon 2004). Southern Bottomlands Natural Region. 242 ha. A preliminary checklist of herbaceous species as reflected in the lack of cyperaceous species and the report of only three grass species. Native species = 125, $C_{av}$ = 3.6, FQI = 40.2; Total species = 138, $C_{av}$ = 3.3, FQI = 38.2.

21a. Upland Prairie Restoration - 1997 (5th year), Grant County. Central Till Plain Natural Region (Bluffton Till Plain Section). 10 ha. Unpublished checklist. Planted in 1993; burned annually, spot herbicide treatment of several aggressive exotic species. Dominant native species include *Andropogon gerardii*, *Ratibida pinnata*, *Monarda fistulosa*, *Desmodium canadense*, and *Silphium* spp. Native species = 36, $C_{av}$ = 3.2, FQI = 19.3; Total species = 65, $C_{av}$ = 1.8, FQI = 14.4.

22b. Upland Prairie Restoration - 2004 (12th year): Native species = 46, $C_{av}$ = 3.7, FQI = 25.1; Total species = 67, $C_{av}$ = 2.5, FQI = 20.8.

23. Versailles State Park Limestone Glade, Ripley County (Homoya 1987). Bluegrass Natural Re-

gion (Switzerland Hills Section). Less than 1 ha. Xeric, rocky slope with stunted trees (primarily *Quercus muhlenbergii*); dominant herbs include *Andropogon gerardii*, *Silphium trifoliatum*, *Physostegia virginiana*, *Lithospermum canescens*, and *Brickellia eupatorioides*. Native species = 80, $C_{av}$ = 4.4, FQI = 39.0; Total species = 83, $C_{av}$ = 4.2, FQI = 38.3.

24. Wabash Breaks Gravel Hill Prairie, Tippecanoe County (Post et al. 1985). Central Till Plain Natural Region (Entrenched Valley Section). Less than 1 ha. See community description under Lookout Point above (No. 12). Native species = 92, $C_{av}$ = 4.3, FQI = 41.0; Total species = 102, $C_{av}$ = 3.9, FQI = 38.9.

25. Wea Creek Gravel Hill Prairie, Tippecanoe County (Post et al. 1985). Central Till Plain Natural Region (Entrenched Valley Section). Less than 1 ha. See community description under Lookout Point above (No. 12). Native species = 76, $C_{av}$ = 4.0, FQI = 35.1; Total species = 89, $C_{av}$ = 3.4, FQI = 32.4.

26. Wening-Sherrit Seep Springs, Dubois County (Homoya 1984). Southwestern Lowlands Natural Region. Less than 1 ha.; pH 5.8-5.9. Mid-canopy of *Toxicodendron vernix* and *Alnus serrulata*; the dominant ferns *Osmunda cinnamomea* and *O. regalis* form hummocks; scattered *Sphagnum*. Native species = 90, $C_{av}$ = 5.3, FQI = 50.7; Total species = 93, $C_{av}$ = 5.2, FQI = 49.9.

27. Wilbur Wright Fish and Wildlife Area (Ruch et al. 2002). Central Till Plain Natural Region (Tipton Till Plain Section). 416 ha. A heterogeneous mix of upland woods, wooded slopes and ravines, seeps and swales, floodplain forest, sedge meadow and marsh, old fields, and wildlife plantings; strong anthropogenic modification and numerous exotic species. This analysis deletes species that were apparently planted but were not spreading. Native species = 388, $C_{av}$ = 3.9, FQI = 77.3; Total species = 536, $C_{av}$ = 2.8, FQI = 65.8.

28. Yellow Birch Ravine Nature Preserve, Crawford County (Yatskievych & Yatskievych 1987). Shawnee Hills Natural Region (Crawford Upland Section). 176 ha. Sandstone bluff and ravines with bottomland dominated by beech-maple forest and drier ridgetops by oaks and hickories; numerous microhabitats; also old fields. Has a history of lumbering and other human disturbance. Native species = 385, $C_{av}$ = 4.6, FQI = 90.4; Total species = 420, $C_{av}$ = 4.2, FQI = 86.5.

## LITERATURE CITED

Alix, M.S. & R.W. Scribailo. 1998. Aquatic plant species diversity and floristic quality assessment of Saugany Lake, Indiana. Proceedings of the Indiana Academy of Science 107:123–139.

Andreas, B.K., J.J. Mack & J.S. McCormac. 2004. Floristic Quality Assessment Index (FQAI) for vascular plants and mosses for the State of Ohio. Ohio Environmental Protection Agency, Division of Surface Water, Wetland Ecology Group, Columbus, Ohio. 219 pp.

Bacone, J.A., L.A. Casebere & M.D. Hutchison. 1983. Glades and barrens of Crawford and Perry counties, Indiana. Proceedings of the Indiana Academy of Sciences 92:367–373.

Basey, G.L. & K.S. Badger. 2004. Structure and composition of plant communities in fire-managed grasslands at Big Oaks National Wildlife Refuge. Proceedings of the Indiana Academy of Science 113:7–16.

Bernthal, T.W. 2003. Development of a floristic quality assessment methodology for Wisconsin. Report to the U.S. EPA (Region V). Wisconsin Department of Natural Resources, Madison, Wisconsin. 19 pp. + appendix.

Blodgett, T.D. & V.L. Riemenschneider. 1983. Vascular plants of Bendix Woods Nature Preserve, St. Joseph County, Indiana. Proceedings of the Indiana Academy of Science 92:375–378.

Ebinger, J.E. & J.A. Bacone. 1981. Vegetation survey of hillside seeps at Turkey Run State Park. Proceedings of the Indiana Academy of Science 90:390–394.

Gray, L.M. & J.A. Bacone. 1979. A floristic survey of Hemlock Bluff Nature Preserve, Jackson County, Indiana. Proceedings of the Indiana Academy of Science 89:372–379.

Herman, K., L. Masters, M. Penskar, A. Reznicek, G. Wilhlem & W. Brodowicz. 1996. Floristic quality assessment system with wetland categories and computer application programs for the State of Michigan. Michigan DNR, Wildlife Division, Natural Heritage Program, Lansing, Michigan. 19 pp. + appendices.

Homoya, M.A. 1987. A floristic survey of a limestone glade in Versailles State Park, Ripley County, Indiana. Proceedings of the Indiana Academy of Science 96:407–412.

Homoya, M.A. 1984. A floristic survey of acid seep springs in Martin and Dubois counties, Indiana. Proceedings of the Indiana Academy of Science 93:323–331.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985. The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94: 245–268.

Mark, R. & S.A. Gordon. 2004. An inventory of the herbaceous plants of the Twin Swamps Nature Preserve, Posey County, Indiana. Proceedings of the Indiana Academy of Science 113:17–25.

Post, T.W. J.A. Bacone & J.R. Aldrich. 1985. Gravel hill prairies of Indiana. Proceedings of the Indiana Academy of Science 94:457–463.

Riemenschneider, V. & P.W. Reed. 1985. Vascular plants of Barker Woods Nature Preserve, LaPorte

County, Indiana. Proceedings of the Indiana Academy of Science 94:465–470.

Rothrock, P.E. 2004. Floristic quality assessment in Indiana: The concept, use, and development of coefficients of conservatism. Final Report for ARN A305-4-53, EPA Wetland Program Development Grant CD975586-01. 96 p. Available at http://www.in.gov/idem/water/planbr/401/publications.html.

Rothrock, P.E. 1997. The vascular flora of Fogwell Forest Nature Preserve, Allen County, Indiana. Proceedings of the Indiana Academy of Science 106:267–290.

Rothrock, P.E., H. Starcs, R. Dunbar & R.L. Hedge. 1993. The vascular flora of Mounds State Park, Madison County, Indiana. Proceedings of the Indiana Academy of Science 102:161–199.

Ruch, D.G., C.R. Reidy, B.G. Torke, K.S. Badger & P.E. Rothrock. 2004. Additions to the flora of Ginn Woods, Delaware County, Indiana. Proceedings of the Indiana Academy of Science 113:1–6.

Ruch, D.G., A. Schoultz & K.S. Badger. 1998. The flora and vegetation of Ginn Woods, Ball State University, Delaware County, Indiana. Proceedings of the Indiana Academy of Science 107:17–60.

Ruch, D.G., B.G. Torke, C.R. Reidy, K.S. Badger & P.E. Rothrock. 2002. The flora and vegetational communities of Wilbur Wright Fish and Wildlife Area, Henry County, Indiana. Proceedings of the Indiana Academy of Science 111: 147–176.

Stonehouse, A.L., K.S. Badger, D.G. Ruch & P.E. Rothrock. 2003. A floristic inventory and description of the structure and composition of the plant communities of Botany Glen, Grant County, Indiana. Proceedings of the Indiana Academy of Science 112:135–159.

Swink, F. & G. Wilhelm. 1994. Plants of the Chicago Region. 4th edition. Indiana Academy of Science, Indianapolis, Indiana. 921 pp.

Swink, F. & G. Wilhelm. 1979. Plants of the Chicago Region. 3rd edition. Morton Arboretum, Lisle, Illinois. 922 pp.

Taft, J., G. Wilhelm, D. Ladd & L. Masters. 1997. Floristic quality assessment for Illinois. Erigenia 15(1):3–97.

Tonkovich, G.S. & M.L. Sargent. 1993. The vascular plants of Fall Creek Gorge Nature Preserve, Warren County, Indiana. Proceedings of the Indiana Academy of Science 102:9–45.

Wilhelm, G.S. & L.A. Masters. 1999. Floristic Quality Assessment Computer Program Version 1.0. Conservation Research Institute, 324 N. York Street, Elmhurst, Illinois 60126.

Yatskievych, G. & K.M. Yatskievych. 1987. A floristic survey of the Yellow Birch Ravine Nature Preserve, Crawford County, Indiana. Proceedings of the Indiana Academy of Science 96:435–445.

*Manuscript received 1 March 2005, revised 16 May 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):19–25

# DISTRIBUTION RECORDS OF SOUTHERN INDIANA VASCULAR PLANTS II

**William E. Thomas**, **Scott P. Ash** and **Richard H. Maxwell**: Herbarium, Indiana University Southeast, New Albany, Indiana 47150 USA

**ABSTRACT.** Ongoing collecting and review of existing collections has resulted in additions to the collection in the Indiana University Southeast Herbarium. New and old collections yielded about 160 new vascular plant county records for Clark, Crawford, Floyd, Harrison, and Jefferson counties in southern Indiana. The Indiana vascular species that are listed as state extirpated, endangered, threatened, or rare are noted. Other species that may become listed, or are otherwise noteworthy, are briefly discussed.

**Keywords:** Vascular plants, Indiana, distribution records

The Indiana University Southeast Herbarium serves as an educational and community resource, as well as a research exchange facility. The herbarium contains vascular plant collections primarily from Clark, Crawford, Floyd, Harrison, and Jefferson counties, with occasional collections from Perry, Scott, and Washington counties. This area of southern Indiana includes the lowermost parts of the following regions: the Mitchell Karst Plain and Knobstone Escarpment sections of the Highland Rim Natural Region and the Shawnee Hills Natural Region (Homoya et al. 1985).

Ongoing collecting and review of existing collections in the herbarium have yielded about 160 new vascular plant county records since the publication of our last distribution list (Maxwell & Thomas 2003). Possible state records and noteworthy collections are listed alphabetically by their scientific names and briefly discussed, followed by state extirpated, endangered, threatened, rare, and watch list species. Table 1 includes distribution records, with their collection vouchers, mainly for Clark, Crawford, Floyd, Harrison, and Jefferson counties. Nomenclature conforms primarily to the *Field Guide to Indiana Wildflowers* (Yatskievych 2000), with authors of plant names, following Brummitt & Powell (1992). Some nomenclature, primarily for ferns, grasses, and common names, is from Mohlenbrock (1986), Gleason & Cronquist (1991), or Yatskievych (2000).

Determination of species status follows the Indiana Natural Heritage Data Center's Endangered, Threatened, and Rare Vascular Plants list, from the Indiana Department of Natural Resources (DNR), Nature Preserves (10 April 1996). Former and present collectors include Indiana University Southeast students, the authors, and several volunteers.

## METHODS

Sites of listed species are reported to the Indiana Department of Natural Resources, Division of Nature Preserves. Vouchers are currently held at the Indiana University Southeast Herbarium. Some collections are sent to Michael A. Homoya, a botanist with the Indiana Department of Natural Resources. Specimens are sent to Dr. George and Kay Yatskievych at the Missouri Botanical Garden as well. Methods and criteria for listing Indiana's extirpated, endangered, threatened, and rare vascular plant species have been discussed by Aldrich et al. (1986).

## POSSIBLE STATE RECORDS AND NOTEWORTHY COLLECTIONS

*Achyranthes japonica* (Miq.) Nakai (Amaranthaceae). Japanese chaff flower. This invasive plant was first reported for Indiana by Maxwell & Thomas (2003). With the collections *W.E. Thomas 1084* and *W.E. Thomas 1745*, Harrison and Jefferson counties are added to the list of Indiana counties known to harbor this weed. Thomas has subsequently collected the species from Jefferson, Carroll, and Meade counties in Kentucky. This plant

Table 1.—State and county records. Abbreviations: SX = State extirpated; SE = State endangered; ST = State threatened; SR = State rare; WL = Watch list; *s.n.* = (*sine numero*) without a number, followed by the collection date.

| Species | Family | County | Collector and number |
|---|---|---|---|
| *Acalypha virginica* L. var. *deamii* Weath. | Euphorbiaceae | Floyd | W.E. Thomas 576 |
| *Achyranthes japonica* (Miq.) Nakai | Amaranthaceae | Harrison | W.E. Thomas 1084 |
| | | Jefferson | W.E. Thomas 1745 |
| *Ammania robusta* Heer & Regel | Lythraceae | Clark | W.E. Thomas 296 |
| | | Crawford | W.E. Thomas 462 |
| *Arabis shortii* (Fernald) Gleason | Brassicaceae | Crawford | W.E. Thomas 694 |
| *Aristolochia serpentaria* L. | Aristolochiaceae | Clark | W.E. Thomas 873 |
| *Bacopa rotundifolia* (Michx.) Wettst. (SE) | Scrophulariaceae | Harrison | W.E. Thomas 1821 |
| *Bidens discoidea* (Torr. & A. Gray) Britton | Asteraceae | Clark | W.E. Thomas 1120 |
| *Brasenia schreberi* J.F. Gmel. | Cabombaceae | Clark | W.E. Thomas 325 |
| | | Harrison | W.E. Thomas 912 |
| *Buglossoides arvense* (L.) I.M. Johnst. | Boraginaceae | Crawford | W.E. Thomas 662 |
| | | Harrison | W.E. Thomas 75 |
| *Cardamine diphyllia* (Michx.) A.W. Wood | Brassicaceae | Clark | R.H. Maxwell 3545 |
| *Cardamine douglassii* (Torr.) Britton | Brassicaceae | Harrison | W.E. Thomas 1224 |
| *Ceratophyllum demersum* L. | Ceratophyllaceae | Clark | L. Townsend *s.n.* July, 1968 |
| *Ceratophyllum echinatum* A. Gray | Ceratophyllaceae | Crawford | W.E. Thomas 939 |
| *Chaenorrhinum minus* (L.) Lange | Scrophulariaceae | Floyd | W.E. Thomas 284 |
| | | Harrison | W.E. Thomas 1411 |
| *Chaerophyllum procumbens* (L.) Crantz var. *procumbens* | Apiaceae | Crawford | W.E. Thomas 699 |
| *Chamaesyce serpens* (Kunth) Small (SX) | Euphorbiaceae | Switzerland | W.E. Thomas 1098 |
| *Chorispora tenella* (Pall.) DC. | Brassicaceae | Floyd | W.E. Thomas 680 |
| *Clematis pitcheri* Torr. & A. Gray (SR) | Ranunculaceae | Harrison | W.E. Thomas 346 |
| *Clinopodium vulgare* L. (SE) | Lamiaceae | Crawford | W.E. Thomas 111 |
| | | Jefferson | W.E. Thomas 1452 |
| *Commelina diffusa* Burm. | Commelinaceae | Floyd | W.E. Thomas 1788 |
| *Cornus obliqua* Raf. (=*C. amomum* Miller var. *schuetzeana* [C.A. Meyer] Rickett) | Cornaceae | Clark | W.R. Adams 8 |
| *Crepis pulchra* L. | Asteraceae | Clark | W.E. Thomas 269 |
| *Cuscuta cephalanthi* Engelm. | Cuscutaceae | Floyd | W.E. Thomas 1611 |
| *Cuscuta coryli* Engelm. | Cuscutaceae | Crawford | W.E. Thomas 1674 |
| *Cuscuta indecora* Choisy | Cuscutaceae | Floyd | W.E. Thomas 1115 |
| *Cyperus echinatus* (L.) Wood | Cyperaceae | Harrison | H.C. Curtis 152 |
| *Desmodium sessilifolium* (Torr.) Torr. & A. Gray | Fabaceae | Crawford | W.E. Thomas 1042 |
| *Dicentra canadensis* (Goldie) Walp. | Fumariaceae | Floyd | W.E. Thomas 739 |
| *Dipsacus laciniatus* L. | Dipsacaceae | Clark | W.E. Thomas 423 |
| *Egeria densa* Planch. | Hydrocharitaceae | Floyd | W.E. Thomas 1836 |
| *Eleocharis quadrangulata* (Michx.) Roem. & Schult. | Cyperaceae | Clark | W.E. Thomas 367 |
| *Erysimum repandum* L. | Brassicaceae | Crawford | W.E. Thomas 698 |
| | | Floyd | W.E. Thomas 678 |
| *Eupatarium hyssopifolium* L. | Asteraceae | Clark | R.H. Maxwell 3035 |
| *Euphorbia obtusata* Pursh (SE) | Euphorbiaceae | Clark | W.E. Thomas 803 |
| | | Scott | H.C. Curtis 73 |
| *Euphobia prostrata* Aiton | Euphorbiaceae | Crawford | W.E. Thomas 566 |
| *Galinsoga quadriradiata* Ruiz & Pav. | Asteraceae | Crawford | W.E. Thomas 601 |
| *Galium pedemontanum* (Bellardi) All. | Rubiaceae | Clark | W.E. Thomas 73 |
| | | Crawford | W.E. Thomas 903 |
| | | Floyd | W.E. Thomas 813 |
| | | Harrison | W.E. Thomas 240 |
| | | Jefferson | W.E. Thomas 786 |

Table 1.—Continued.

| Species | Family | County | Collector and number |
|---|---|---|---|
| *Geranium dissectum* L. | Geraniaceae | Floyd | W.E. Thomas 210 |
| | | Jefferson | W.E. Thomas 788 |
| *Geum lacinatum* Murray | Rosaceae | Clark | W.E. Thomas 896 |
| | | Crawford | W.E. Thomas 847 |
| | | Floyd | W.E. Thomas 259 |
| *Gratiola virginiana* L. | Scrophulariaceae | Clark | W.E. Thomas 47 |
| *Holosteum umbellatum* L. | Caryophyllaceae | Floyd | W.E. Thomas 649 |
| | | Harrison | W.E. Thomas 1262 |
| *Houstonia pusilla* Schoepf | Rubiaceae | Crawford | W.E. Thomas 665 |
| *Humulus japonicas* Siebold & Zucc. | Cannabaceae | Harrison | W.E. Thomas 1430 |
| *Humulus lupulus* L. | Cannabaceae | Clark | W.E. Thomas 1491 |
| *Hydrocotyle sibthorpioides* Lam. | Apiaceae | Clark | W.E. Thomas 324 |
| | | Floyd | W.E. Thomas 1157 |
| *Hypericum drummondii* (Grev. & Hook.) Torr. & A. Gray | Clusiaceae | Clark | R.H. Maxwell 3363 |
| *Hypericum sphaerocarpum* Michx. | Clusiaceae | Crawford | W.E. Thomas 386 |
| *Ipomoea coccinea* L. | Convolvulaceae | Floyd | W.E. Thomas 540 |
| *Ipomoea lacunosa* L. | Convolvulaceae | Crawford | W.E. Thomas 596 |
| | | Harrison | Wanda Pindell 2 |
| *Iva annua* L. | Asteraceae | Floyd | W.E. Thomas 1079 |
| *Iva xanthifolia* Nutt. | Asteraceae | Clark | Thomas & Maxwell 605 |
| | | Floyd | W.E. Thomas 1114 |
| *Lemna minor* L. | Lemnaceae | Floyd | D.W. Taylor 253 |
| *Ludwigia decurrens* Walter (SR) | Onagraceae | Crawford | W.E. Thomas 456 |
| | | Harrison | W.E. Thomas 130 |
| *Ludwigia leptocarpa* (Nutt.) H. Hara | Onagraceae | Clark | W.E. Thomas 614 |
| | | Crawford | W.E. Thomas 1734 |
| | | Floyd | W.E. Thomas 583 |
| *Ludwigia peploides* (Kunth) P.H. Raven subsp. *glabrescens* (Kuntze) P.H. Raven | Onagraceae | Floyd | W.E. Thomas 1650 |
| | | Harrison | W.E. Thomas 1046 |
| *Lunaria rediviva* L. | Brassicaceae | Clark | W.E. Thomas 1295 |
| *Lythrum alatum* Pursh | Lythraceae | Clark | W.E. Thomas 327 |
| *Lythrum salicaria* L. | Lythraceae | Crawford | W.E. Thomas 461 |
| | | Floyd | W.E. Thomas 292 |
| | | Jefferson | W.E. Thomas 999 |
| *Matricaria recutita* L. | Asteraceae | Floyd | W.E. Thomas 749 |
| *Matricaria discoidea* DC. | Asteraceae | Crawford | W.E. Thomas 795 |
| *Mirabilis jalapa* L. | Nyctaginaceae | Clark | W.E. Thomas 1018 |
| *Mirabilis nyctaginea* (Michx.) MacMill. | Nyctaginaceae | Floyd | J. Loftin 67 |
| *Monotropa uniflora* L. | Pyrolaceae | Floyd | Alice Evans 2 |
| *Myosotis arvensis* (L.) Hill | Boraginaceae | Harrison | W.E. Thomas 953 |
| *Myosotis macrosperma* Engelm. | Boraginaceae | Crawford | W.E. Thomas 829 |
| | | Harrison | W.E. Thomas 71 |
| | | Jefferson | W.E. Thomas 878 |
| *Myosotis stricta* Link *ex* Roem. & Schult. | Boraginaceae | Clark | W.E. Thomas 1302 |
| | | Floyd | W.E. Thomas 727 |
| *Myosoton aquaticum* (L.) Moench | Caryophyllaceae | Crawford | W.E. Thomas 902 |
| *Myriophyllum spicatum* L. | Haloragidaceae | Clark | W.E. Thomas 1495 |
| | | Scott | W.E. Thomas 1518 |
| *Najas guadalupensis* (Spreng.) Magnus | Najadaceae | Clark | W.E. Thomas 1832 |
| *Najas gracillima* (A. Braun *ex* Engelm.) Magnus (SE) | Najadaceae | Crawford | W.E. Thomas 1814 |
| | | Harrison | W.E. Thomas 1738 |

Table 1.—Continued.

| Species | Family | County | Collector and number |
|---|---|---|---|
| *Najas minor* All. | Najadaceae | Crawford | W.E. Thomas & H.C. Curtis 1743 |
| | | Harrison | W.E. Thomas 1827 |
| | | Floyd | W.E. Thomas 1837 |
| *Osmorhiza longistylis* (Torr.) D.C. | Apiaceae | Crawford | W.E. Thomas 810 |
| *Oxalis illinoensis* Schwegman | Oxalidaceae | Harrison | Maxwell & Thomas 3552 |
| *Passiflora incarnata* L. | Passifloraceae | Crawford | W.E. Thomas 1676 |
| *Pluchea camphorata* (L.) DC. | Asteraceae | Harrison | W.E. Thomas 545 |
| *Polygonum cuspidatum* Siebold & Zucc. | Polygonaceae | Floyd | W.E. Thomas 541 |
| | | Harrison | W.E. Thomas 133 |
| | | Jefferson | W.E. Thomas 1447 |
| *Potentilla norvegica* L. | Rosaceae | Harrison | W.E. Thomas 241 |
| *Ranunculus ficaria* L. | Ranunculaceae | Crawford | W.E. Thomas 663 |
| *Ranunculus micranthus* Nutt. | Ranunculaceae | Clark | Lisa Brinksneader *s.n.* 6 April 1986 |
| | | Harrison | W.E. Thomas 1225 |
| *Ranunculus sceleratus* L. | Ranunculaceae | Floyd | W.E. Thomas 260 |
| *Rubus phoenicolasius* Maxim. | Rosaceae | Crawford | W.E. Thomas 1409 |
| | | Floyd | R.H. Maxwell 3556 |
| | | Harrison | W.E. Thomas 1479 |
| *Rudbeckia laciniata* L. var. *laciniata* | Asteraceae | Floyd | W.E. Thomas 1066 |
| *Sagina decumbens* (Elliott) Torr. & A. Gray | Caryophyllaceae | Floyd | W.E. Thomas 162 |
| *Sagittaria australis* (J.G. Sm.) Small (SR) | Alismataceae | Floyd | W.E. Thomas 1162 |
| *Sagittaria graminea* Michx. | Alismataceae | Clark | W.E. Thomas 396 |
| *Salsola kali* L. | Chenopodiaceae | Clark | R.H. Maxwell 1573 |
| *Scutellaria lateriflora* L. | Lamiaceae | Floyd | W.E. Thomas 1116 |
| *Selaginella eclipes* Buck | Selaginellaceae | Harrison | W.E. Thomas 101 |
| *Silphium perfoliatum* L. | Asteraceae | Crawford | W.E. Thomas 981 |
| *Sparganium eurycarpum* Engelm. *ex* A. Gray | Sparganiaceae | Clark | W.R. Adams 10 |
| | | Crawford | W.E. Thomas 404 |
| *Spirodela polyrhiza* (L.) Schleid. | Lemnaceae | Crawford | W.E. Thomas 938 |
| *Stellaria corei* Shinners | Caryophyllaceae | Clark | R.H. Maxwell 2939 |
| *Stellaria longifolia* Muhl. *ex* Willd. | Caryophyllaceae | Clark | W.E. Thomas 94 |
| *Strophostyles leiosperma* (Torr. & A. Gray) Piper (ST) | Fabaceae | Floyd | R.H. Maxwell 2210 |
| *Thlaspi alliaceum* L. | Brassicaceae | Clark | W.E. Thomas 654 |
| | | Floyd | W.E. Thomas 1270 |
| *Torilis arvensis* (Huds.) Link | Apiaceae | Clark | R.H. Maxwell 1815 |
| | | Crawford | W.E. Thomas 980 |
| | | Floyd | W.E. Thomas 906 |
| | | Harrison | W.E. Thomas 956 |
| | | Jefferson | W.E. Thomas 944 |
| *Tragia cordata* Michx. (SR) | Euphorbiaceae | Lawrence | W.E. Thomas 126 |
| *Tragopogon dubius* Scop. | Asteraceae | Crawford | Lance Stroud 98 |
| | | Floyd | Gohmann & Weatherholt 100 |
| *Triosteum perfoliatum* L. | Caprifoliaceae | Harrison | H.C. Curtis 46 |
| *Typha angustifolia* L. | Typhaceae | Clark | W.E. Thomas 987 |
| | | Harrison | W.E. Thomas 1429 |
| *Valerianella chenopodifolia* (Pursh.) DC. (SE) | Valerianaceae | Harrison | W.E. Thomas 805 |
| | | Jefferson | W.E. Thomas 782 |
| *Valerianella locusta* (L.) Betcke | Valerianaceae | Floyd | W.E. Thomas 206 |
| | | Harrison | W.E. Thomas 760 |

Table 1.—Continued.

| Species | Family | County | Collector and number |
|---|---|---|---|
| *Valerianella radiata* (L.) Dufr. | Valerianaceae | Floyd | W.E. Thomas 214 |
| | | Harrison | W.E. Thomas 783 |
| *Valerianella umbilicata* (Sull.) Wood | Valerianaceae | Crawford | W.E. Thomas 806 |
| *Verbesina virginica* L. (SE) | Asteraceae | Crawford | W.E. Thomas 590 |
| *Veronica anagallis-aquatica* L. (WL) | Scrophulariaceae | Floyd | W.E. Thomas 329 |
| | | Harrison | W.E. Thomas 1817 |
| *Veronica hederaefolia* L. | Scrophulariaceae | Clark | Maxwell & Thomas 3544 |
| *Veronica officinalis* L. | Scrophulariaceae | Clark | W.E. Thomas 231 |
| *Veronica persica* Poir. | Scrophulariaceae | Floyd | W.E. Thomas 655 |
| | | Harrison | W.E. Thomas 652 |
| | | Jefferson | W.E. Thomas 1197 |
| *Veronica polita* Fr. | Scrophulariaceae | Harrison | W.E. Thomas 151 |
| *Veronica serpyllifolia* L. | Scrophulariaceae | Clark | R.H. Maxwell 2244 |
| | | Floyd | R.H. Maxwell 3136 |
| *Wolffia brasiliensis* Wedd. | Lemnaceae | Crawford | W.E. Thomas 1731 |
| | | Floyd | W.E. Thomas 1583 |
| | | Harrison | W.E. Thomas 638 |

appears to be spreading along the Ohio River floodplain.

*Ceratophyllum echinatum* A. Gray (Certophyllaceae). Coontail. Found in a small pond just west of Wyandotte Lake in Crawford County, this species is under consideration for state endangered/threatened/rare status by the Department of Natural Resources (Homoya pers. commun.).

*Cuscuta indecora* Choisy (Cuscutaceae). Collared dodder. Found in a low floodplain woods along the Ohio River in New Albany, Floyd County, this native species is just entering our area. We consider *W.E. Thomas 1115*, the state record voucher.

*Egeria densa* Planch. (Hydrocharitaceae). Brazilian water-weed. A likely aquarium escapee, the first report of this species for the state was a site in Crawford County (Maxwell & Thomas 2003). A second population was found in Floyd County in the large lake at the Mount Saint Francis Retreat Center.

*Euphorbia prostrata* Aiton (Euphorbiaceae). Prostrate spurge. A small cluster of this tiny spurge was found in the cracks of a concrete boat ramp at the Old Dam 44 in Harrison County on the Ohio River. Gleason (Gleason & Cronquist 1991) calls this species "rarely adventive (from southern U.S.) and probably not persistent in our range." We consider *W.E. Thomas 566*, the state record voucher.

*Lunaria rediviva* L. (Brassicaceae). Honesty. A small population of this ornamental species was found growing on a high ridge in Clark State Forest. We consider *W.E. Thomas 1295*, the state record voucher. The origin of these plants is unknown.

*Torilis arvensis* (Hudson) Link (Apiaceae). Hedge-parsley. The collection *R.H. Maxwell 1815* from Clark County was originally reported as *T. japonica* (Houtt.) DC by R.H. Maxwell (1981). The specimen has since been determined to be *T. arvensis* (Hudson) Link. As far as we know *T. japonica* has not been found in Clark County.

## INDIANA STATE EXTIRPATED (SX)

*Chamaesyce serpens* (Kunth) Small (Euphorbiaceae). Matted broomspurge. A small colony was found in late 2003 at Markland Locks and Dam complex in Switzerland County. The plants were growing on large ballast rocks in the low flood beach area of the Ohio River. The site was visited again by Thomas during the 2004 season and found to be essentially unchanged.

## INDIANA STATE ENDANGERED (SE)

*Bacopa rotundifolia* (Michx.) Wettst. (Scrophulariaceae). Round-leaved water-hyssop. A small population of perhaps three plants was discovered under the Ohio River bridge just east of Mauckport in Harrison County. The site is a muddy parking lot.

*Clinopodium vulgare* L. (Lamiaceae). Dogmint. Several populations were found in Crawford County within the Harrison-Crawford State Forest. Additionally, a large population was discovered by Thomas in Jefferson County along a utility easement within the Splinter Ridge Wildlife Management Area.

*Euphorbia obtusata* Pursh (Euphorbiaceae). Blunt-leaved spurge. A small population was found in Clark County by Thomas in a roadside ditch along State Highway 31 near the entrance to Clark State Forest. A larger site was later discovered by Howell Curtis within the state forest boundaries. Additional populations were found in Scott County by both Thomas and Curtis.

*Najas gracillima* (A. Braun *ex* Engelm.) Magnus (Najadaceae). Thread-like naiad. Three new populations found in Harrison County and one in Crawford County, all within the Harrison-Crawford State Forest. All four sites were small ponds, likely remnants of old homesteads.

*Ranunculus harveyi* (A. Gray) Britton (Ranunculaceae). Harvey's buttercup. During an April 2003 survey of the proposed Budd Road Woodlands Park for the New Albany Floyd County Park Board, a cluster of about 12 Harvey's buttercup were found by Dr. David W. Taylor. Thomas found an additional cluster a few days later. The sites are on an upper, sparsely wooded ridge of the knobs in the segment of the park to be preserved by a forest management and conservation easement in favor of *The Nature Conservancy*.

*Valerianella chenopodifolia* (Pursh) DC. (Valerianaceae). Goosefoot cornsalad. During the 2003 season a small population was found by Thomas in Jefferson County near the Splinter Ridge WMA. Populations were later found by Curtis at two sites in Harrison County, one at Tobacco Landing along the Ohio River, and a much larger population at Harrison-Crawford State Forest. In the 2004 season yet another population was found roadside in Harrison County just west of Mauckport.

*Verbesina virginica* L. (Asteraceae). Frostweed. Several plants were found by Thomas along the Ohio River at Old Dam 44 park/boat ramp in Crawford County just west of the mouth of the Blue River.

## INDIANA STATE THREATENED (ST)

*Strophostyles leiosperma* (Torr. & A. Gray) Piper (Fabaceae). Small-flowered woollybean. A small colony was located on the Indiana University Southeast campus in Floyd County.

## INDIANA STATE RARE (SR)

*Clematis pitcheri* Torr. & A. Gray (Ranunculaceae). Pitcher's leatherflower. Found along the higher banks of Mosquito Creek north of New Boston in Harrison County.

*Ludwigia decurrens* Walter (Onagraceae). Primrose-willow. This species was found to be occasional along the Ohio River floodplain in both Harrison and Crawford counties.

*Sagittaria australis* (J.G. Sm.) Small (Alismataceae). Long-beaked arrowhead. A small colony of this species was found in a New Albany city park, Floyd County.

*Tragia cordata* Michx. (Euphorbiaceae). Heart-leaved noseburn. Found along the roadside at Spring Mill State Park in Lawrence County.

## INDIANA STATE WATCH LIST (WL)

*Veronica anagallis-aquatica* L. (Scrophulariaceae). Water speedwell. This plant was found at two sites along the Ohio River floodplain in the New Albany area, Floyd County, and was also collected from the rocky bed of Indian Creek in downtown Corydon, Harrison County.

## ACKNOWLEDGMENTS

We wish to thank Dr. David W. Taylor, Curator of the Indiana University Southeast Herbarium (JEF), for use of the facilities and his encouragement. We thank Michael A. Homoya, Botanist, and others in the Indiana Department of Natural Resources for their continual encouragement and assistance in the search for listed species in southern Indiana and their concern for the preservation of our natural heritage. Thanks also to Gerald J. Pagac, Director of the Division of State Parks and Reservoirs, for providing a collection permit to Maxwell for Charlestown State Park and to Ben Hubbard, Program Director Indiana Division of Forestry, who provided a collection permit for Clark and Harrison-Crawford State Forests. We also appreciate the cooperation of the following Property Managers: Larry Gray of Charlestown Park; Pete Thorn of Harrison-Crawford State Forest; and Walt Zak of Clark State Forest. Special thanks to Drs. George and Kay Yatskievych of the Missouri Botanical Garden for their ongoing help in determining and confirming identifications of Indiana flora. Thanks also to Dr. Lytton Musselman of Old Dominion University for his *Cuscuta* determination.

## LITERATURE CITED

Aldrich, J.R., J.A. Bacone & M.A. Homoya. 1986. List of extirpated, endangered, threatened, and rare vascular plants in Indiana: An update. Proceedings of the Indiana Acadamy of Science 95: 413–41.

Brummitt, R.K. & C.E. Powell. 1992. Authors of Plant Names. Royal Botanic Gardens. Kew.

Deam, C.C. 1940. Flora of Indiana. Department of Conservation, Indianapolis, Indiana. 1236 pp.

Division of Nature Preserves. 1996. Endangered, threatened, and rare vascular plant species documented from Indiana. Web site, http://www.in.gov/dnr/naturepr/endanger/plant.html Indianapolis, Indiana.

Gleason, H.A. & A. Cronquist. 1991. Manual of the Vascular Plants of Northeastern United States and adjacent Canada. 2nd ed. New York Botanic Gardens. Bronx, New York. 910 pp.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985. The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94: 245–268.

Maxwell, R.H. 1981. Indiana Plant Distribution Records. Proceedings of the Indiana Academy of Science 91:502–503.

Maxwell, R.H. & W.E. Thomas. 2003. Distribution Records of Southern Indiana Vascular Plants Proceedings of the Indiana Academy of Science. 112 (1):22–28.

Mohlenbrock, R.H. 1986. Guide to the Vascular Flora of Illinois. Southern Illinois University Press. Carbondale & Edwardsville, Illinois. 507 pp.

Yatskievych, K. 2000. Field Guide to Indiana Wildflowers, Indiana University Press. Bloomington and Indianapolis. 357 pp.

*Manuscript received 19 January 2005, revised 9 February 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):26–32

# A VASCULAR PLANT INVENTORY OF HOWELL WETLANDS, A NATURE PRESERVE WITHIN THE CITY OF EVANSVILLE, INDIANA

**Jennifer Keller**, **Edith Hardcastle** and **Scott A. Gordon**: 8600 University Boulevard, Department of Biology, University of Southern Indiana, Evansville, Indiana 47712 USA

**ABSTRACT.** Howell Wetlands is a 9.3 hectare park located in the city of Evansville, Indiana. The park includes an oxbow lake and a bottomland hardwood plant community that is at the northern-most edge of its distribution. This study describes an inventory of flowering plant species collected during the growing season of 2004, as well as a list of plants collected in previous years. A total of 129 species was documented in this study. GPS coordinates were collected for each plant during the growing season of 2004 in order to facilitate continuing restoration efforts and are included on the voucher specimens. Despite the presence of invasive plants like *Phragmites australis* and *Lonicera japonica*, Howell Wetlands contains three species that merit special concern: *Rubus enslenii* (state endangered), *Taxodium distichium* (state threatened), and *Passiflora incarnata* (state rare).

**Keywords:** Howell Wetlands, Indiana, flora, rare plants

Indiana once had 2.3 million hectares of wetlands. Today, only 15% of the original wetlands remains, the rest having been cleared for agriculture and urban development (Myers 1997). Indiana ranks 4th among the 50 states in the proportion of wetlands lost (Dahl 1990). Preservation of remaining wetland habitats is a top priority of state and federal agencies because they provide essential ecosystem services including flood control, water purification, and wildlife habitat (Myers 1997). The city of Evansville, Indiana, located in Vanderburgh County, is situated on the banks of the Ohio River and still contains many acres of wetland habitat.

Howell Wetlands, a 9.3 hectare wetland park was added to the City of Evansville Parks and Recreation Department in 1999 and is managed by Wesselman Nature Society. Howell Wetlands is one of only five urban wetland parks that exist in Indiana (City of Evansville 2005). This wetland community was much abused and various areas had been used as a dump before it became protected. Howell Wetlands now has walking trails and a park manager who provides educational programs and tours. The park has become a resource for the city of Evansville providing environmental education and habitat for a variety of wetland plants and animals (Fig. 1). In addition, it serves as a component of the "ecological internet" in that it is part of the greenspace in Evansville that provides corridors for plant and animal migration (Jackson 1997). Howell Wetlands now consists of an original core habitat that was left intact as well as a section of newly "restored" wetlands (Fig. 2).

In 1978 work began to clean up significant amounts of garbage, household sewage and oil from area homes and businesses. The Army Corps of Engineers contributed $485,000 to the project, which the City of Evansville matched. The original wetlands still in existence include an oxbow lake formed from the nearby Ohio River and associated bottomland hardwood forest. The reconstructed wetlands habitat was constructed on old farmland adjacent to the oxbow lake and consists of two lakes (created by the Army Corps of Engineers) as well as a wildflower meadow that was intended to display native Indiana prairie vegetation. Part of the intent of this study is to document plants in the original oxbow lake and bottomland hardwood forest section of the wetlands (Fig. 2). The list of plants and their precise locations compiled in this study will be used as a guide in the restoration of original vegetation in degraded areas of the park.

Conservation of any nature preserve is aid-

Figure 1.—Habitat of Howell Wetlands.

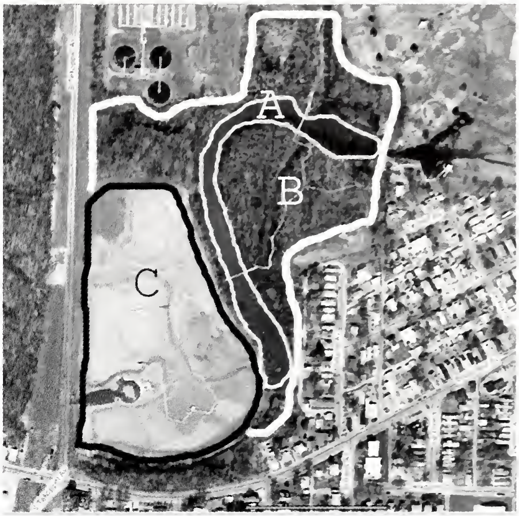


Figure 2.—Aerial photograph of Howell Wetlands. A = oxbow lake, B = original wetland community surrounding oxbow, C = "new" reclaimed wetlands.

ed by a comprehensive survey of biodiversity to provide baseline data on species present in order for managers to recognize decline of indigenous species as well as the spread of exotic invasive species. For the past 10 years, botany students from the University of Southern Indiana (USI) have inventoried the plant species of Howell Wetlands and deposited these specimens in the herbarium at USI. Until now, these collection records have only been maintained as an internal list, and no effort has been made to make them into a formal publication. The purpose of this study was to systematically sample, identify and publish vascular plant species at Howell Wetlands through the growing season of 2004. In addition, we wanted to make available the list of plants collected during previous surveys at this same site and vouchered in the USI herbarium (USIH).

## METHODS

During the 2004 growing season, vascular plants were collected to document species in the original oxbow lake habitat of Howell Wetlands. Collections were made on a weekly basis beginning in April and ending in September. The specimens were pressed, identified, and mounted on herbarium paper. The primary reference books used for identification include Steyermark (1963), Deam (1940), Yatskievych (2000), and Radford et al. (1968). The current scientific name for each species was found using the USDA plants database. The voucher specimens are stored in the USIH. A GPS unit was used to document the specific location of each specimen collected. GPS coordinates were included on the voucher specimens in the USIH. The USDA plants database was used to determine which species were native or introduced and if they were threatened, rare, or endangered. A publication from the Indiana Native Plant and Wildflower Society was used to verify which exotic species were particularly invasive in Indiana.

## RESULTS AND DISCUSSION

The herbaceous plants that were collected and identified from Howell Wetlands during the years 1995, 1997, and 2004 are listed in the appendix. The list includes 129 species representing 105 genera and 58 families. Species that were collected previously, for which multiple herbarium specimens were found, are indicated with an asterisk (*). Species collected and identified by James Sanders in 1995 are indicated with the initials "JS" in the herbarium number. Species collected and identified by Jeremy Meuth in 1997 are indicated with the initials "JM" in the herbarium number.

Howell Wetlands is a component of the Southern Bottomlands Natural Region (Homoya et al. 1985). This region is comprised of bottomland forest, swamps, ponds, and sloughs. These natural communities, while widespread in the southern United States, reach their northern most range in southern Indiana, and as such, contain flora components more closely associated with the lower Mississippi Valley and Gulf Coastal Plain of the southern United States.

Significant species collected from this study that are threatened, rare, or endangered are *Taxodium distichum* L., (S2) threatened in Indiana; *Passiflora incarnata* L., (S1) rare in Indiana; and *Rubus flagellaris* Willd., (S1) endangered in Indiana. These three species, while rare in the state, still have a widespread distribution south of Indiana. Even so, species at the edges of their range merit conservation concern because populations of these species may be genetically distinct from populations in the center of their ranges and may therefore hold a unique component of genetic diversity (Lesica & Allendorf 1995). In addition, when a species undergoes decline, many times it occurs from the center of the range outwards leaving only edge populations as reservoirs to provide for recovery (Furlow 1995).

Invasive species in a natural area are always of concern, particularly if the area is located in an urban setting where adjacent properties provide many exotic species opportunity for invasion. Invasive species collected at Howell Wetlands include, *Cirsium arvense* L., *Lonicera japonica* Thunb., *Melilotus officinalis* L., *Glechoma hederacea* L., *Phragmites australis* Cav. Steud., *Lysimachia nummularia* L., and *Rosa multiflora* Thunb. The invasive species most abundant at Howell Wetlands were *Lonicera japonica* Thunb. and *Rosa multiflora* Thunb. The presence of exotic species is not surprising considering the history of disturbance at Howell Wetlands. However, there is still a diverse native flora present at Howell Wetlands despite the presence of these exotic invaders.

## ACKNOWLEDGMENT

We would like to acknowledge and express our gratitude to Paul Bouseman, Botanical Curator at Mesker Park Zoo & Botanic Garden for including us in his conservation efforts. We would like to thank Tommy Donahue, Project Manager of Howell Wetlands for allowing us to do this study and for taking us by canoe to collect specimens located on an island. We would also like to extend our thanks to Eric Knox, Director of the Indiana University Herbarium for his time and assistance in identifying difficult species. We would like to acknowledge former USI students Jeremy Mueth and James Sanders, for their earlier research at Howell Wetlands.

## APPENDIX

## CATALOG OF VASCULAR PLANTS OF HOWELL WETLANDS

Vascular plants collected from 1995 to 2004 by Jennifer J. Keller, James Sanders, and Jeremy Meuth, and not previously published are listed here. Each species report contains the following information: (1) scientific name; (2) common name; (3) the designation of native or exotic; (4) a designation of rare, threatened, or endangered if appropriate; (5) date of flowering; and (6) the USIH herbarium number. A "JS" number indicates the specimen was collected by James Sanders in 1995. A "JM" number indicates the specimen was collected by Jeremy Meuth in 1997. All other herbarium numbers indicate a specimen collected in 2004 by Jennifer Keller. Species collected by Jennifer Keller that were previously collected by Sanders or Meuth have a herbarium number preceded by an asterisk (*). Species are listed following the taxonomic scheme in the USDA plants database.

### DIVISION EQUISETOPHYTA

Equisetaceae (Horsetail Family)

*Equisetum arvense* L.: Field horsetail; native; April; M1.

### DIVISION PTERIDOPHYTA

Aspleniaceae (Spleenwort Family)

*Asplenium platyneuron* (L.) B.S.P.: Ebony spleenwort; native; JS21.

### DIVISION PINOPHYTA

Cupressaceae (Cypress Family)

*Juniperus virginiana* L.: Red cedar; native; JM15.

Taxodiaceae (Redwood Family)

*Taxodium distichum* (L.) L.C. Rich.: Bald cypress; native; threatened; T11.

### DIVISION MAGNOLIOPHYTA

Aceraceae (Maple Family)

*Acer negundo* L.: Boxelder; native; JS1.
*Acer saccharinum* L.: Silver maple; native; JM1.
*Acer saccharum* Marsh.: Sugar maple; native; JS2.
*Acer rubrum* L.: Red maple; native; JM2.

Alismataceae (Water-plantain Family)

*Sagittaria latifolia* Willd.: Common arrowhead; native; marshy area; August; F56.

### Anacardiaceae (Sumac Family)

*Rhus copallinum* L.: Shining sumac; native; JM12.
*Rhus glabra* L.: Smooth sumac; native; growing along bank; June; *T10.

### Annonaceae (Custard-apple Family)

*Asimina triloba* (L.) Dunal: Pawpaw; native; JM7.

### Apiaceae (Carrot Family)

*Chaerophyllum procumbens* (L.) Crantz: Wild chervil; native; April–May; F18.
*Cicuta maculata* L.: Water hemlock; native; JM13.
*Daucus carota* L.: Queen Anne's lace; introduced; May–June; F30.
*Heracleum maximum* Bartr.: Cow parsnip; native; April; location; F13.
*Osmorhiza longistylis* (Torr.) DC.: Anise root; native; April–May; F17.
*Sanicula canadensis* L.: Black snakeroot; native; May; F22.

### Aquifoliaceae (Holly Family)

*Ilex opaca* Ait.: American holly; native; JS8.

### Asclepiadaceae (Milkweed Family)

*Asclepias incarnata* L.: Swamp milkweed; native; marshy area; July; *F42.
*Asclepias syriaca* L.: Common milkweed; native; June; F32.

### Asteraceae (Aster Family)

*Ageratina altissima* (L.) King & H.E. Robins.: White snakeroot; native; JM3.
*Ambrosia artemisiifolia* L.: Common ragweed; native; JM4.
*Bidens connata* Muhl. *ex* Willd.: Beggar ticks; native; September–October; growing in marshy area; F68.
*Cirsium arvense* (L.) Scop.: Canada thistle; introduced; invasive; JS9.
*Erigeron annuus* (L.) Pers.: Daisy fleabane; native; May; F25.
*Erigeron pulchellus* Michx.: Robin's plantain; native; April; F14.
*Eupatorium perfoliatum* L.: Thoroughwort; native; August; *F50.
*Euthamia graminifolia* (L.) Nutt.: Flat-topped goldenrod; native; August–September; *F58.
*Lactuca floridana* (L.) Gaertn.: Blue lettuce; native; August; sparse; F60.
*Packera glabella* (Poir) C. Jeffrey: Butterweed; native; April; F15.
*Solidago canadensis* L.: Tall goldenrod; native; September; F63.
*Solidago nemoralis* Ait.: Field goldenrod; native; JS10.
*Sonchus asper* (L.) Hill: Spiny-leaved sow; introduced; July; F37.
*Symphyotrichum ericoides* (L.) Nesom: Wreath aster; native; September; F65.
*Symphyotrichum lateriflorum* (L.) A. & D. Love: White woodland aster; native; August; F52.
*Verbesina alternifolia* (L.) Britt. *ex* Kearney: Yellow ironweed; native; August–September; F57.
*Vernonia gigantea* (Walt.) Trel.: Ironweed; native; August; growing in marshy area; *F55.
*Xanthium strumarium* L.: Cocklebur; native; JS12.

### Balsaminaceae (Touch-me-not Family)

*Impatiens capensis* Meerb.: Spotted touch-me-not; native; May–June; *F31.

### Berberidaceae (Barberry Family)

*Berberis thunbergii* DC.: Japanese barberry; introduced; JM8.
*Podophyllum peltatum* L.: Mayapple; native; JS18.

### Betulaceae (Birch Family)

*Carpinus caroliniana* Walt.: American hornbeam; native; JM14.

### Bignoniaceae (Trumpet-creeper Family)

*Bignonia capreolata* L.: Cross vine; native; JM6.
*Campsis radicans* (L.) Seem. *ex* Bureau: Trumpet vine; native; May–June; *M3.

### Boraginaceae (Borage Family)

*Myosotis macrosperma* Engelm.: Largeseed forget-me-not; native; April; F12.

### Brassicaceae (Mustard Family)

*Cardamine hirsuta* L.: Bittercress; introduced; April; F4.

### Campanulaceae (Bellflower Family)

*Lobelia cardinalis* L.: Cardinal flower; native; August; growing near water; *F44.
*Lobelia inflata* L.: Indian tobacco; native; JM5.
*Triodanis perfoliata* (L.) Nieuwl.: Venus looking-glass; native; May; F26.

### Caprifoliceae (Honeysuckle Family)

*Lonicera japonica* Thunb.: Japanese honeysuckle; introduced; invasive; May; very abundant; V5.
*Lonicera sempervirens* L.: Trumpet honeysuckle; native; April; V2.
*Sambucus canadensis* (L.) R. Bolli: Common elderberry; native; June; T8.

### Caryophyllaceae (Pink Family)

*Cerastium fontanum* Baumg.: Common mouse-ear chickweed; introduced; April; F6.
*Dianthus armeria* L.: Deptford pink; introduced; May; *F27.
*Stellaria pubera* Michx.: Great chickweed; native; April–May; *F20.

### Commelinaceae (Spiderwort Family)

*Commelina communis* L.: Dayflower; introduced; September; location; F62.

*Tradescantia virginiana* L.: Spiderwort; native; JM16.

### Convolvulaceae (Morning-glory Family)

*Ipomoea pandurata* (L.) G.F.W. Mey.: Wild potato vine; native; July; V9.

### Cornaceae (Dogwood Family)

*Cornus florida* L.: Dogwood; native; April; T1, T7.

### Cyperaceae (Sedge Family)

*Cyperus* sp. L.: Sedge; native; September–October; growing in marshy area; F69.

### Dioscoreaceae (Yam Family)

*Dioscorea villosa* L.: Wild yamroot; native; JM17.

### Fabaceae (Pea Family)

*Apios americana* Medik.: Groundnut; native; August; F51.

*Cercis canadensis* L.: Redbud; native; April; T5.

*Desmodium obtusum* (Muhl. *ex* Willd.) DC.: Stiff ticktrefoil; native; August; F53.

*Desmodium paniculatum* (L.) DC.: White-flowered ticktrefoil; native; August; *F61.

*Melilotus officinalis* (L.) Lam.: Yellow sweet clover; introduced; invasive; May–June; F23, F28.

*Senna marilandica* (L.) Link: Wild senna; native; August; F46.

*Strophostyles helvula* (L.) Ell.: Trailing fuzzybean; native; August; V10.

*Trifolium campestre* Schreb.: Large hop clover; introduced; April–May; F19.

### Fagaceae (Beech Family)

*Quercus coccinea* Muenchh.: Scarlet oak; native; JS6.

*Quercus imbricaria* Michx.: Shingle oak; native; JS5.

*Quercus velutina Lam.: Black oak; native; JS3.*

*Quercus prinus* L.: Chestnut oak; native; JS4.

### Fumariaceae (Fumitory Family)

*Corydalis flavula* (Raf.) DC.: Pale corydalis; native; April; F7.

### Gentianaceae (Gentian Family)

*Sabatia angularis* (L.) Pursh: Rosepink; native; JS20.

### Geraniaceae (Geranium Family)

*Geranium carolinianum* L.: Cranesbill; native; May; F29.

### Hamamelidiaceae (Witch-hazel Family)

*Liquidambar styraciflua* L.: Sweet gum; native; JM10.

### Iridaceae (Iris Family)

*Sisyrinchium atlanticum* Bickn.: Blue-eyed grass; native; April–May; F16.

### Lamiaceae (Mint Family)

*Glechoma hederacea* L.: Ground ivy; introduced; invasive; April; F2.

*Lamium purpureum* L.: Dead nettle; introduced; April; F5.

*Prunella vulgaris* L.: Heal-all; native; July; growing in wooded area; *F39.

*Scutellaria lateriflora* L.: Mad-dog skullcap; native; August, growing in marshy area; F48.

### Lauraceae (Laurel Family)

*Sassafras albidum* (Nutt.) Nees: Sassafras; native; April; *T4.

### Lemnaceae (Duckweed Family)

*Lemna minor* L.: Lesser duckweed; native; F70.

### Malvaceae (Mallow Family)

*Hibiscus moscheutos* L.: Rose mallow; native; June–July; *F38.

### Menispermaceae (Moonseed Family)

*Menispermum canadense* L.: Common moonseed; native; JM9.

### Oleaceae (Olive Family)

*Fraxinus americana* L.: White ash; native; JS23.

### Onagraceae (Evening primrose Family)

*Calylophus serrulatus* (Nutt.) Raven: Yellow sundrops; native; August; F59.

*Ludwigia alternifolia* L.: Seedbox; native; JM20.

*Ludwigia peploides* (Kunth) Raven: Floating primrose willow; native; September; growing in marshy area; F64.

### Oxalidaceae (Wood-sorrel Family)

*Oxalis stricta* L.: Common yellow oxalis; native; April–May; *F21.

### Passifloraceae (Passionflower Family)

*Passiflora incarnata* L.: Purple passionflower; native; rare; June; *F34.

*Passiflora lutea* L.: Yellow passionflower; native; JM19.

### Phytolaccaceae (Pokeweed Family)

*Phytolacca americana* L.: Pokeweed; native; July; F41.

### Poaceae (Grass Family)

*Dichanthelium clandestinum* (L.) Gould: Deertongue; native; May; M2.

*Hordeum jubatum* L.: Foxtail; native; JS25.

*Phragmites australis* (Cav.) Trin. *ex* Steud.: Reed; native; invasive; JS22.

### Polygonaceae (Buckwheat Family)

*Polygonum hydropiperoides* Michx.: Water pepper; native; JM11.

*Polygonum pensylvanicum* L.: Pinkweed; native; September; *F67.

*Polygonum punctatum* Ell.: Water smartweed; native; July; growing in marshy area; F43.

*Polygonum scandens* L.: Climbing buckwheat; native; September; *F66.

### Portulacaceae (Purslane Family)

*Claytonia virginica* L.: Spring beauty; native; April; F1.

### Primulaceae (Primrose Family)

*Lysimachia nummularia* L.: Moneywort; introduced; invasive; May; F24.

### Ranunculaceae (Buttercup Family)

*Clematis terniflora* DC.: Autumn clematis; introduced; August; F54.

*Ranunculus abortivus* L.: Small-flowered crowfoot; native; April; *F8.

### Rosaceae (Rose Family)

*Agrimonia parviflora* Ait.: Agrimony; native; August; *F49.

*Amelanchier arborea* (Michx. f.) Fern.: Shadbush; native; April; *V1.

*Geum canadense* Jacq.: White avens; native; JM22.

*Geum virginianum* L.: Cream-colored avens; native; June–July; F35.

*Prunus* sp. L.: Plum; April; T3.

*Prunus americana* Marsh.: Wild plum; native; April; T2.

*Prunus virginiana* L.: Chokecherry; native; April; T6.

*Rosa multiflora* Thunb. *ex* Murr.: Multiflora rose; introduced; invasive; May; abundant; *V7.

*Rosa setigera* Michx.: Prairie rose; native; May–June; V8.

*Rubus allegheniensis* Porter: Blackberry; native; JM21.

*Rubus argutus* Link: High-bush blackberry; native; May; V6.

*Rubus flagellaris* Willd.: Dewberry; native; endangered; April; V3.

*Rubus occidentalis* L.: Black raspberry; native; April–May; V4.

### Rubiaceae (Madder Family)

*Cephalanthus occidentalis* L.: Buttonbush; native; July; *T9.

*Diodia virginiana* L.: Buttonweed; native; June; *F33.

*Galium concinnum* Torr. & Gray: Shining bedstraw; native; April; F11.

### Salicaceae (Willow Family)

*Populus deltoides* Bartr. *ex* Marsh.: Eastern cottonwood; native; JS29.

*Salix nigra* Marsh.: Black willow; native; JS30.

### Scrophulariaceae (Figwort Family)

*Mimulus alatus* Ait.: Monkey flower; native; August; F47.

### Solanaceae (Potato Family)

*Solanum carolinense* L.: Horsenettle; native; June–July; *F36.

### Smilacaceae (Catbrier Family)

*Smilax glauca* Walt.: Sawbrier; native; JM18.

### Urticaceae (Nettle Family)

*Boehmeria cylindrica* (L.) Sw.: False nettle; native; July; *F40.

### Verbenaceae (Verbena Family)

*Phyla lanceolata* (Michx.) Greene: Fogfruit; native; August; F45.

### Violaceae (Violet Family)

*Viola bicolor* Pursh: Johnny-jump-up; native; April; F9.

*Viola sororia* Willd.: Common blue violet; native; April; *F3.

### Vitaceae (Grape Family)

*Parthenocissus quinquefolia* (L.) Planch.: Virginia creeper; native; JS28.

## LITERATURE CITED

City of Evansville Parks and Recreation Department. 2005. http://www.vanderburghgov.org/home/index.asp?page=578. Evansville, Indiana.

Dahl, T.E. 1990. Wetland losses in the United States, 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 13 pp.

Deam, C. 1940. Flora of Indiana. Dept. of Conserv., Wm. B. Burford Co. Indianapolis, Indiana. 1236 pp.

Furlow, F.B. 1995. Life in the margins: Emphasis on local species diversity has over-shadowed an important aspect of reserve design. The American Naturalist 124:255–279.

Homoya, M.A., D.B. Abrell, J.R. Aldrich & T.W. Post. 1985 The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94: 245–268.

Indiana Wetlands Conservation Plan. 1996. Indiana Department of Natural Resources. Indianapolis, Indiana. 75 pp.

Jackson, M.T. 1997. The future of natural Indiana: Can we imagine it? Guide it? *In* The Natural Heritage of Indiana (M.T. Jackson, ed.). Indiana University Press. Bloomington, Indiana. 482 pp.

Lesica, P. & F.W. Alendorf. 1995. When are peripheral populations valuable for conservation? Conservation Biology 9:753–760.

Myers, E. 1997. An endangered natural resource: Wetlands. *In* The Natural Heritage of Indiana

(M.T. Jackson, ed.). Indiana University Press. Bloomington, Indiana. 482pp.

Radford, A.E., H.E. Ahles & C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press. Chapel Hill, North Carolina. 1183 pp.

Steyermark, J.A. 1963. Flora of Missouri. Iowa State University Press. Ames, Iowa. 1728 pp.

USDA, NRCS. 2004. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Louisiana. 70874-4490 USA.

Yatskievych, K. 2000. Field Guide to Indiana Wildflowers. Indiana University Press. Bloomington, Indiana. 357 pp.

*Manuscript received 5 February 2005, revised 25 March 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):33–42

# FRESHWATER MUSSEL (BIVALVIA: UNIONIDAE) SURVEY OF THE BROUILLETTS CREEK BASIN IN ILLINOIS AND INDIANA

**Jeremy S. Tiemann:** Illinois Natural History Survey, 607 East Peabody Drive, Champaign, Illinois 61820 USA

**ABSTRACT.** The freshwater mussel assemblage of Brouilletts Creek basin in eastern Illinois and western Indiana was sampled at 35 sites for 55 person-hours. A total of 765 live individuals of 20 species was collected, including the state-listed little spectaclecase (*Villosa lienosa*); seven additional species were represented only as valves, including three state-listed (spike (*Elliptio dilatata*), round hickorynut (*Obovaria subrotunda*), and kidneyshell (*Ptychobranchus fasciolaris*)), and one federally-endangered species (clubshell (*Pleurobema clava*)). This survey describes the status of the assemblage and provides baseline data if disturbances should occur in the basin.

**Keywords:** Mollusca, survey, stream habitat, Wabash River

Freshwater mussels (Bivalvia: Unionidae) are a vital component of stream ecosystems (Strayer & Smith 2003). Their sensitivity to stream habitats and their sessile, filter-feeding habits allow them to be good biological indicators of stream integrity. They play an important role in aquatic ecosystems by providing a food source for many animals, including muskrats (*Ondatra zibethicus*), raccoons (*Procyon lotor*) and fishes (e.g., redear sunfish (*Lepomis microlophus*) and freshwater drum (*Aplodinotus grunniens*)). Their valves provide habitat for algae and aquatic insect larvae and provide nests and refugia for certain species of fishes, such as madtoms (*Noturus* spp.). In addition, freshwater mussels help stabilize stream substrate against the scouring effects of floods.

North American freshwater mussels have undergone a drastic decline during the past century (Williams et al. 1993), and have become one of the most imperiled groups of animals. Nearly two-thirds of the approximate 300 species are extinct, federally-listed as endangered or threatened, or are in need of conservation status. Several factors are responsible for the decline in freshwater mussels, including anthropogenic disturbances to stream habitats (e.g., habitat destruction and water quality problems), commercial harvest, and invasion of exotic species (e.g., zebra mussel (*Dreissena polymorpha*).

The drastic decline in freshwater mussels also applies to streams in the midwestern United States. For instance, the number of live species in the Wabash River has dropped from its historical count of 72 to its post-1969 count of 29 (Cummings & Mayer 1997). However, not all drainages in the midwestern United States have been sufficiently sampled to assess the fauna. One such example is Brouilletts Creek basin in the Wabash River drainage. Prior to this project, no comprehensive study on the freshwater mussel assemblage of Brouilletts Creek basin had been conducted, and both historical and current data on the fauna consequently were limited. Freshwater mussels in Brouilletts Creek basin were sampled with the objective of obtaining data on the present distribution and structure (e.g., richness and relative abundance) of the assemblage.

## METHODS

**Description of study area.**—Brouilletts Creek is located within the Wabash Border Natural Division (Page et al. 1992). The creek originates in the southeast corner of Vermilion County and the northeast corner of Edgar County, Illinois, and flows southeast through Vermillion County, Indiana, before depositing its waters in the Wabash River approximately 3.5 km east of Shepardsville in Vigo County, Indiana (Fig. 1; Appendix 1). Brouilletts

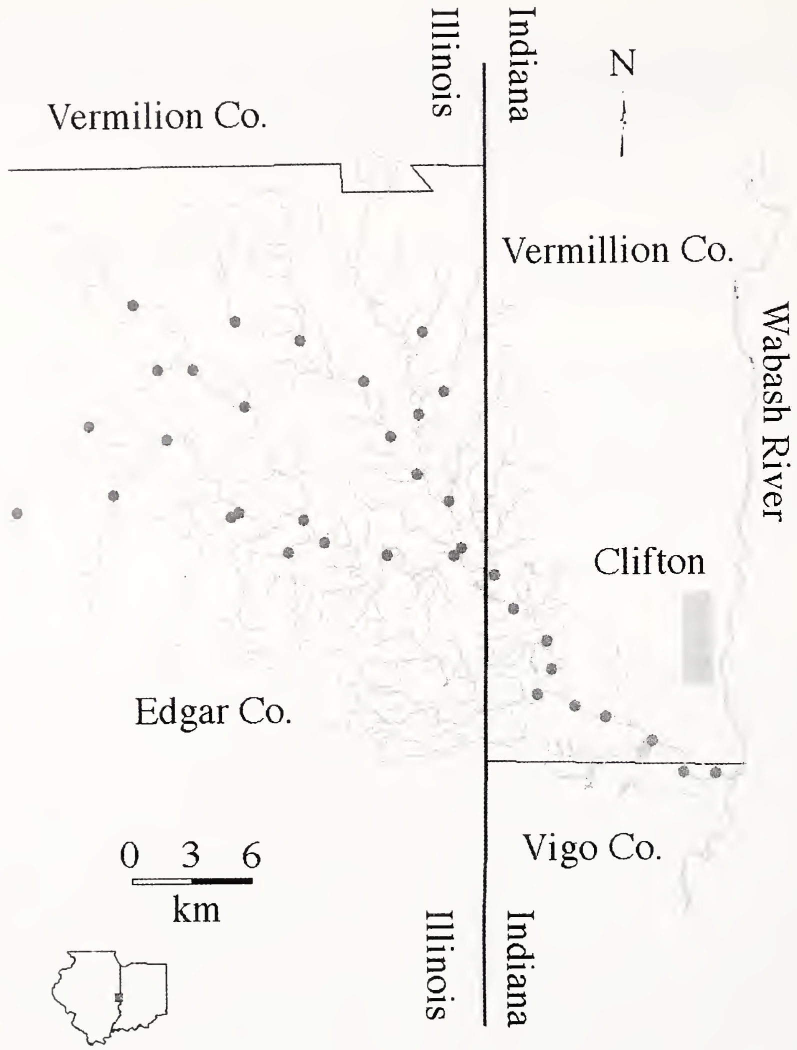


Figure 1.—Map of Brouilletts Creek and its principal tributaries. Dots indicate collecting location sites for the 2004 Brouilletts Creek basin freshwater mussel survey in Illinois and Indiana.

Creek has a total basin area of approximately 900 km$^2$ with nearly 650 km$^2$ occurring in Illinois. Prior to this survey, 18 species of freshwater mussels were known from the basin (Table 1); of those species, three are state-listed in Illinois and/or Indiana: spike (*Elliptio dilatata*), kidneyshell (*Ptychobranchus fasciolaris*), and little spectaclecase (*Villosa lienosa*), with only *V. lienosa* having been collected alive (data were taken from Call [1896] and from the Illinois Natural History Survey (INHS) Mollusk Collection, Champaign on 1 January 2004).

**Mussel survey methodology.**—A freshwater mussel survey of Brouilletts Creek basin in eastern Illinois and western Indiana was conducted at 35 sites from 2 September 2004 to 4 October 2004 (except one site, which was sampled on 28 April 2004). Live freshwater mussels and valves of dead specimens were collected by hand-grabbing for 1 or 2 person-hours at each site. The timed-search technique is the most effective method for obtaining data on relative abundance and species richness, especially for rare species (Vaughn 2003). At each site, live individuals were identified, measured (shell length), aged (external growth rings), and if possible, sexed while noting

Table 1.—Native freshwater mussels of Brouilletts Creek basin in Illinois and Indiana. Site totals are the number of sites where the species was collected either as live (L) or only as valves of dead specimens (V) during this survey. Also included are the total numbers of live individuals of each species, and whether a species was added to the basin list as a result of this survey (×), where historic data were taken from Call (1896) and from the Illinois Natural History Survey Mollusk Collection, Champaign on 1 March 2004. Special status of the freshwater mussels includes FE = U.S. federally-endangered, IL-SE = Illinois state-endangered, IN-SE = Indiana state-endangered, IL-ST = Illinois state-threatened, and IN-SSC = Indiana-state-special-concern.

| Scientific name | Common name | Status | New to basin list | Site totals | No. of indiv. |
|---|---|---|---|---|---|
| Anodontinae | | | | | |
| *Anodontoides ferussacianus* (Lea 1834) | Cylindrical papershell | | | L(8), V(10) | 24 |
| *Lasmigona complanata* (Barnes 1823) | White heelsplitter | | | L(7), V(5) | 8 |
| *Lasmigona compressa* (Lea 1829) | Creek heelsplitter | | | L(5), V(4) | 10 |
| *Lasmigona costata* (Rafinesque 1820) | Flutedshell | | × | L(0), V(3) | 0 |
| *Pyganodon grandis* (Say 1829) | Giant floater | | | L(3), V(5) | 6 |
| *Strophitus undulatus* (Say 1817) | Creeper | | | L(10), V(5) | 40 |
| *Utterbackia imbecillis* (Say 1829) | Paper pondshell | | × | L(1), V(0) | 1 |
| Ambleminae | | | | | |
| *Amblema plicata* (Say 1817) | Threeridge | | | L(2), V(8) | 5 |
| *Elliptio dilatata* (Rafinesque 1820) | Spike | IL-ST | | L(0), V(1) | 0 |
| *Fusconaia flava* (Rafinesque 1820) | Wabash pigtoe | | | L(15), V(5) | 52 |
| *Pleurobema clava* (Lamarck 1819) | Clubshell | IL-SE, IN-SE, & FE | × | L(0), V(2) | 0 |
| *Quadrula pustulosa* (Lea 1831) | Pimpleback | | × | L(0), V(2) | 0 |
| *Quadrula quadrula* (Rafinesque 1820) | Mapleleaf | | × | L(1), V(0) | 3 |
| *Tritogonia verrucosa* (Rafinesque 1820) | Pistolgrip | | × | L(2), V(1) | 2 |
| *Uniomerus tetralasmus* (Say 1831) | Pondhorn | | | L(3), V(3) | 9 |
| Lampsilinae | | | | | |
| *Actinonaias ligamentina* (Lamarck 1819) | Mucket | | | L(0), V(1) | 0 |
| *Lampsilis cardium* Rafinesque 1820 | Plain pocketbook | | | L(20), V(2) | 240 |
| *Lampsilis siliquoidea* (Barnes 1823) | Fatmucket | | | L(20), V(5) | 185 |
| *Lampsilis teres* (Rafinesque 1820) | Yellow sandshell | | | L(10), V(4) | 27 |
| *Leptodea fragilis* (Rafinesque 1820) | Fragile papershell | | | L(11), V(2) | 99 |
| *Ligumia subrostrata* (Say 1831) | Pondmussel | | | L(0), V(0) | 0 |
| *Obovaria subrotunda* (Rafinesque 1820) | Round hickorynut | IL-SE & IN-SSC | × | L(0), V(4) | 0 |
| *Potamilus alatus* (Say 1817) | Pink heelsplitter | | × | L(2), V(0) | 2 |
| *Potamilus ohiensis* (Rafinesque 1820) | Pink papershell | | × | L(2), V(2) | 8 |
| *Ptychobranchus fasciolaris* (Rafinesque 1820) | Kidneyshell | IL-SE & IN-SSC | | L(0), V(2) | 0 |
| *Toxolasma parvus* (Barnes 1823) | Lilliput | | | L(6), V(7) | 8 |
| *Truncilla donaciformis* (Lea 1828) | Fawnsfoot | | × | L(1), V(0) | 1 |
| *Villosa lienosa* (Conrad 1834) | Little spectaclecase | IL-ST & IN-SSC | | L(6), V(12) | 35 |

signs of reproduction, before being returned alive to the stream. Voucher specimens of all species from each site were deposited in the INHS Mollusk Collection. An effort was made to sample all available habitats, but particular emphasis was placed on areas that appeared likely to support freshwater mussels; also, because the mudpuppy (*Necturus maculosus*) has been found in the basin (Petzing et al. 2002), a conscious effort was made to look in pockets of silt and sand under cobble for the state-listed (Illinois state-endangered and Indiana state-special-concern) salamander mussel (*Simpsonaias ambigua*), which uses *N. maculosus* as a host (Watters 1994). Species were identified using Cummings & Mayer (1992); for nomenclature, the list of common and scientific names of mollusks prepared by the Council of Systematic Malacologists and the Committee on Scientific and Common Names of the American Malacological Union was followed (Turgeon et al. 1998), except for the recognition of subspecies.

**Habitat survey methodology.**—Instream habitat was assessed at each site from 25 October 2004 to 19 November 2004. Transects were established at 5 m intervals along the length of the area sampled for freshwater mussels. Points were then spaced 1 m apart on the streambed along each transect and substrate composition, substrate compaction, and stream velocity were calculated (Tiemann et al. 2004). Substrate composition was assessed by scraping the surface of the substrate with a spade shovel and visually estimating the contents as proportions of clay/silt, sand, gravel, pebble, cobble, and boulder. Substrate compaction was coded by touch, where scores were either 1 (loose), 2 (moderate), or 3 (firm). Stream velocity was measured at 60% water depth using a Swoffer Model 2100 current meter (Swoffer Instruments, Inc.; Seattle, Washington). For each variable at each site, scores were averaged from all points to acquire a mean site instream habitat description.

## RESULTS

**Freshwater mussel survey.**—In 55 person-hours, 765 live individuals of 20 species, including the state-listed *V. lienosa*, were collected; an additional seven species, including three state-listed species and one federally-endangered species, also were found but only as valves (Table 1; Appendix 1). Plain pocketbook (*Lampsilis cardium*), fat mucket (*Lampsilis siliquoidea*), and fragile papershell (*Leptodea fragilis*) were the most abundant species collected in terms of live individuals (Table 1; Appendix 2). *Lampsilis cardium*, *L. siliquoidea*, and Wabash pigtoe (*Fusconaia flava*) were found alive at the most number of sites (Table 1; Appendix 2). *Villosa lienosa* was the only listed species (either at the state or federal level) collected alive in the basin. Thirty-five live individuals of *V. lienosa* were found (Fig. 2) at six sites (all of which were in Illinois), and valves were discovered at an additional 12 sites (Table 1; Appendix 2). The only historic freshwater mussel of Brouilletts Creek basin not found either alive or dead was the pondmussel (*Ligumia subrostrata*), which was reported by Call (1896) from "Bruiett's Creek, Vigo County" in Indiana; however, a voucher specimen for this record could not be found. In addition, although specifically targeted, *S. ambigua* was not found in the basin.

Live individuals were found at 28 sites, and valves were found at an additional six; one site did not have any evidence of freshwater mussels (Appendix 2). The number of live individuals per site varied from 0–87; the number of live species per site varied from 0–10, whereas the number of total species per site varied from 0–17 (Appendix 2).

**Habitat survey.**—Habitat in Brouilletts Creek basin was highly variable. The headwaters of the mainstem were a continuous series of compacted silt-laden substrates (mainly clay/silt and cobble) with sluggish flows, but changed to a series of moderately compacted, free-flowing sandy, cobble riffles and compacted sandy pools with lethargic flows near its confluence with the Wabash River. Tributaries were a series of riffles and pools with compacted clay/silt and cobble substrates with minimal flow in their headwaters, but changed to a series of loosely compacted, free-flowing gravel riffles and compacted clay/silt substrate pools with lethargic flows near their confluences with the mainstem.

## DISCUSSION

**Freshwater mussel survey.**—For its size, Brouilletts Creek basin supports a highly diverse freshwater mussel fauna with 20 extant species. This number is similar to the number reported for North Fork Vermilion River basin (Wabash River drainage) in Illinois/Indiana,

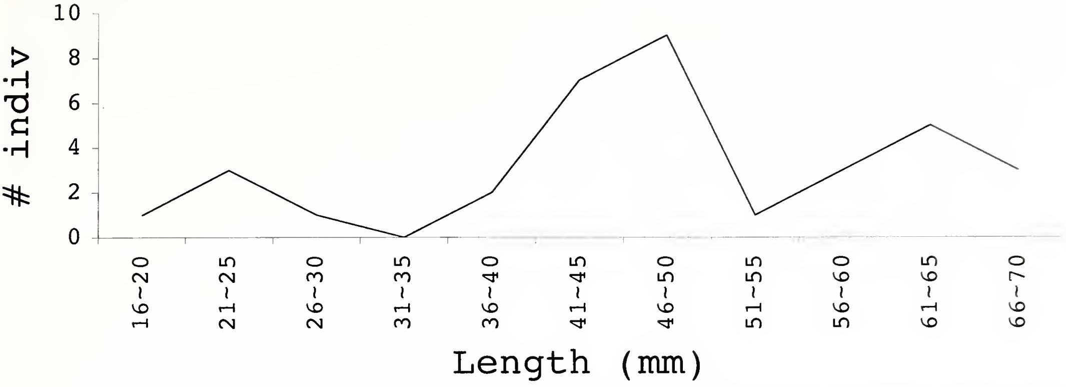


Figure 2.—Length frequency distribution (mm) for *Villosa lienosa* during the 2004 Brouilletts Creek basin survey.

which has been described as one of the most diverse streams in the midwestern United States, with 23 extant species in a basin size of 762 km$^2$ (Szafoni et al. 2000). The 28 total species is equivalent to the number recorded for Wildcat Creek (Wabash River drainage) in Indiana, which was called an exceptional stream with 26 total species in a basin size of 2085 km$^2$ (Myers-Kinzie et al. 2001). The 28% decline in present-day species richness compared to historical data is analogous to the other principal tributaries of the Wabash River (Tippecanoe = 33%, Vermilion = 29%, Embarras = 27%, and Little Wabash = 30%), all of which are some of the midwestern U.S.'s most species-rich streams (Cummings & Berlocher 1990; Cummings & Mayer 1997).

Seven species were represented only by relict valves. One species, the flutedshell (*Lasmigona costata*), has been described as uncommon-to-rare in the area (Cummings et al. 1998), whereas four others are listed at the state or federal level (Table 1). The federally-endangered clubshell (*Pleurobema clava*), which once was widely scattered in smaller streams in the upper Wabash River drainage, is now disappearing from much of its historical range (Cummings & Berlocher 1990). A similar trend is apparent with three state-listed species: *E. dilatata*, round hickorynut (*Obovaria subrotunda*), and *P. fasciolaris* (Cummings & Mayer 1997). The last two species, pimpleback (*Quadrula pustulosa*) and mucket (*Actinonaias ligamentina*), represented only as valves during this survey are common, but sporadic, throughout their ranges in Illinois (Cummings & Mayer 1997). The only historic species not found was *L. subrostrata*, which was interesting because this species is still found in smaller streams in adjacent basins (Cummings & Mayer 1997).

The freshwater mussel assemblage of Brouilletts Creek basin appears to be moderately stable. Based on size class distributions, growth rings, and sexual morphological features, several species (e.g., *L. cardium*, *L. siliquoidea*, and *L. fragilis*) appear to be thriving and reproducing in the basin. However, other species (e.g., threeridge (*Amblema plicata*), pistolgrip (*Tritogonia verrucosa*), and fawnsfoot (*Truncilla donaciformis*)) appear imperiled in the basin, whereas others (e.g., *E. dilatata*, *P. clava*, and *P. fasciolaris*) apparently have been extirpated from the basin. These trends might be the result of specific habitat and/or fish host requirements present in the basin.

The high diversity is surprising considering that smaller basins typically do not offer as much habitat or potential fish hosts as larger nearby drainages (Cummings et al. 1998; Szafoni et al. 2000). High freshwater mussel diversity often is associated with high fish diversity (Szafoni et al. 2000). Brouilletts Creek basin historically has supported at least 50 fish species (data were taken from the INHS Fish Collection, Champaign on 7 May 2004). Some fish hosts might only use Brouilletts Creek basin during the spawning season and would therefore provide little opportunity for continued existence of certain species. It was beyond the scope of this study to determine whether the distributions and abundances of fish hosts were sufficient to facilitate the subsistence of any of the eight freshwater mussel species no longer found in Brouilletts Creek basin. A comprehensive fish survey would provide better data of the status of this assemblage.

One species of note is *V. lienosa*, which was present at 51% of the sites surveyed (Appendix 2). This percentage is comparable to that of the Middle Branch of the North Fork of the Vermilion River, which supports one of the largest populations in Illinois (Szafoni et al. 2000). Based on length frequency distributions, (Fig. 2), three size classes appear to be evident. Eight individuals were between 61–68 mm, which is approaching or exceeding the maximum size of about 64 mm for *V. lienosa* (Cummings & Mayer 1992); five individuals were less than 27 mm. These data suggest that *V. lienosa* is successfully reproducing in the basin. Fish hosts have not been determined for *V. lienosa*, but a congeneric species, the rainbow (*Villosa iris*), is known to use the black basses (*Micropterus* spp.) and the rock bass (*Ambloplites rupestris*) as hosts (Watters 1994). If these fishes also were hosts for *V. lienosa*, then potential hosts in Brouilletts Creek basin include smallmouth bass (*M. dolomieu*), spotted bass (*M. punctulatus*), largemouth bass (*M. salmoides*) and *A. rupestris* (data were taken from the INHS Fish Collection on 7 May 2004).

Competition from exotic mollusk species appears to be minimal in Brouilletts Creek basin at the present time. The Asian clam (*Corbicula fluminea*) was found only in the lower portions of the basin (downstream from the Illinois-Indiana state line). Also, no *D. polymorpha* was found; however, it has been reported in the Wabash River in Vermillion County, Indiana (INHS Mollusk Collection #22458), and could be a potential future threat.

**Habitat survey.**—The majority of the habitat in Brouilletts Creek basin was sandy gravel/pebble with some cobble present; this type of habitat is favorable to freshwater mussels (Cummings & Mayer 1992). However, some degree of habitat destruction from anthropogenic disturbances (e.g., construction projects, intensive farming practices, and all-terrain-vehicles (ATV) trails) was evident in several areas. Habitat destruction might be the most important threat to freshwater mussels (Williams et al. 1993). Freshwater mussels generally are intolerant to environmental perturbations and tend to concentrate pollutants in their tissues due to their sessile filter-feeding habits (Cummings & Mayer 1992).

Various construction projects, including bridge construction and gravel mining, were occurring throughout Brouilletts Creek basin. Bridge construction, without proper siltation control measures, has been shown to cause alterations of substrate composition and substrate compaction in streams (Tiemann 2004); and gravel mining has been suggested to degrade habitat by increasing siltation (Vaughn 2003). Destabilization of substrate might be the most important factor in freshwater mussel decline by reducing habitat and interfering with respiration, excretion, feeding, reproduction, and juvenile recruitment (Obermeyer et al. 1997).

Several poor farming practices occur in Brouilletts Creek basin that can alter stream environments. For example, some areas completely lacked intact riparian zones. Riparian zones help reduce erosion, and removal of these areas can increase sediment loads in streams and occlude interstitial spaces in substrate (Tiemann 2004). Also, some areas had agricultural crops planted to the edge of the stream banks. This practice has been shown to result in increased siltation and agricultural pollution (Hoke 2004). Another example of destructive farming practices is cattle watering in streams. Unimpeded access of livestock to streams can pollute the water, alter the substrate, and crush freshwater mussels (Hoke 2004).

Certain recreational activities create a potential threat to freshwater mussels via instream habitat degradation. The use of ATVs on the streambed was evident in the lower portions of Brouilletts Creek basin. As with unimpeded access of cattle, unrestricted access of ATVs to streambeds can cause alteration of habitats by compacting and/or destabilizing substrates and crushing shells of freshwater mussels.

Brouilletts Creek basin has not been impounded by man-made dams; however, several beaver dams were present throughout the basin. Although these dams are small and not permanent, lowhead dams (< 4 m) have been shown to modify habitat, such as changing flow and substrate conditions (Tiemann et al. 2004). As with most natural and anthropogen-

## APPENDIX 1

Collecting location sites for the 2004 Brouilletts Creek basin freshwater mussel survey in Illinois and Indiana. FWM is native freshwater mussel material, if any, collected at that site during this survey (L = those species collected alive, V = those species collected only as valves, and the numbers in parentheses indicate how many species were represented either as live or only as valves during this survey).

| Site no. | State: Country | Stream | Common location | Latitude, Longitude | FWM |
|---|---|---|---|---|---|
| 01 | Illinois: Edgar | Brouilletts Creek | 2 mi NNW Cherry Point | 39.8227N, 87.7471W | L(7), V(1) |
| 02 | | Brouilletts Creek | 2 mi WSW Chrisman | 39.7926N, 87.7114W | L(4), V(3) |
| 03 | | Brouilletts Creek | 2.5 mi S Chrisman | 39.7756N, 87.6800W | L(7), V(5) |
| 04 | | Brouilletts Creek | 3.5 mi E Horace | 39.7220N, 87.6446W | L(8), V(2) |
| 05 | | Brouilletts Creek | 2 mi SW Logan | 39.7118N, 87.6325W | L(8), V(2) |
| 06 | | Brouilletts Creek | 3.75 mi NW Hunter | 39.7058N, 87.5949W | L(7), V(1) |
| 07 | | Brouilletts Creek | 2 mi W St. Bernice, IN | 39.7052N, 87.5547W | L(3), V(6) |
| 08 | | Shiloh No. 3 Ditch | 0.5 mi NW Garland | 39.7256N, 87.8168W | L(0), V(1) |
| 09 | | Shiloh No. 3 Ditch | 2.25 mi SE Metcalf | 39.7663N, 87.7735W | L(4), V(2) |
| 10 | | Shiloh No. 3 Ditch | 2.75 mi WSW Chrisman | 39.7922N, 87.7323W | L(8), V(1) |
| 11 | | South Fork Brouilletts Creek | 1.25 mi ENE Horace | 39.7256N, 87.6838W | L(3), V(2) |
| 12 | | South Fork Brouilletts Creek | 3 mi S Cherry Point | 39.7598N, 87.7271W | L(3), V(4) |
| 13 | | South Fork Brouilletts Creek | 2.25 mi WNW Horace | 39.7339N, 87.7588W | L(3), V(0) |
| 14 | | Willow Creek | 1 mi E Horace | 39.7233N, 87.6886W | L(1), V(2) |
| 15 | | Snake Creek | 1.5 mi NE county airport | 39.7076N, 87.6545W | L(1), V(1) |
| 16 | | North Fork Brouilletts Creek | 1 mi NW Chrisman | 39.8149N, 87.6859W | L(1), V(0) |
| 17 | | North Fork Brouilletts Creek | 1.5 mi E Chrisman | 39.8062N, 87.6470W | L(0), V(1) |
| 18 | | North Fork Brouilletts Creek | 1.75 mi S Scottland | 39.7870N, 87.6084W | L(2), V(0) |
| 19 | | North Fork Brouilletts Creek | 3 mi S Scottland | 39.7614N, 87.5926W | L(7), V(3) |
| 20 | | North Fork Brouilletts Creek | 4.5 mi SSE Scottland | 39.7434N, 87.5765W | L(3), V(4) |
| 21 | | North Fork Brouilletts Creek | 1.75 mi N Clays Prairie | 39.7090N, 87.5499W | L(7), V(4) |
| 22 | | Salt Fork Brouilletts Creek | 2.5 mi SSE Scottland | 39.7716N, 87.5754W | L(0), V(3) |
| 23 | | Bonwell Branch | 1.75 mi ENE Scottland | 39.8100N, 87.5731W | L(0), V(1) |
| 24 | | Lick Run | 2.75 mi SE Scottland | 39.7821N, 87.5603W | L(0), V(1) |
| 25 | | Goose Creek | 2.75 mi SE Logan | 39.7307N, 87.5576W | L(0), V(1) |
| 26 | Indiana: Vermillion | Brouilletts Creek | 1.25 mi N Blanford | 39.6816N, 87.5213W | L(10), V(2) |
| 27 | | Brouilletts Creek | 1.25 mi E Blanford | 39.6655N, 87.4991W | L(4), V(7) |
| 28 | | Brouilletts Creek | 1.25 mi SE Centenary | 39.6521N, 87.4959W | L(6), V(0) |
| 29 | | Brouilletts Creek | 2 mi S Centenary | 39.6348N, 87.4823W | L(6), V(6) |
| 30 | | Brouilletts Creek | 1.25 mi NW Universal | 39.6302N, 87.4635W | L(3), V(14) |
| 31 | | Brouilletts Creek | 1.25 mi E Universal | 39.6190N, 87.4363W | L(4), V(6) |
| 32 | | Little Creek | 0.5 mi W West Clinton | 39.6963N, 87.5303W | L(0), V(0) |
| 33 | | Coal Creek | 2 mi SSE Blanford | 39.6407N, 87.5046W | L(2), V(2) |
| 34 | Indiana: Vigo | Brouilletts Creek | 0.5 mi N Shepardsville | 39.6041N, 87.4173W | L(9), V(3) |
| 35 | | Brouilletts Creek | 1 mi E Shepardsville | 39.6036N, 87.3987W | L(4), V(3) |

## APPENDIX 2

Native freshwater mussels collected by site during the 2004 Brouilletts Creek basin in Illinois and Indiana. "Site number" is the site number, which is referenced in Appendix 1. Numbers within a given species row represent the number of individuals for that species that was collected alive, "D" indicates those species collected only as fresh dead specimens, and "R" signifies those species collected only as relict specimens.

| Species | Site number | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | |
| Subfamily Anodontinae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Anodontoides ferussacianus* | 6 | | 1 | | 2 | | | | R | 1 | R | D | | R | | 1 | | 2 | 6 | D | 5 | | | | R | R | | | R | R | | | R | | | 24 |
| *Lasmigona complanata* | | 1 | 1 | | 2 | | | | | 1 | | R | | | | | | | 1 | R | | | | | | 1 | | | R | R | R | | | 1 | | 8 |
| *Lasmigona compressa* | 2 | D | 2 | 3 | | | D | | R | D | | | | | | | | | 2 | | 1 | | | | | | | | | | | | | | | 10 |
| *Lasmigona costata* | | | | R | | | | | | | | | | | | | | | | | | | | | | | | | | R | R | | | | | 0 |
| *Pyganodon grandis* | 3 | | 2 | | | | | | | | R | | | | | | | | | R | D | | | | | | | | R | R | | | 1 | R | | 6 |
| *Strophitus undulatus* | | | R | | D | 2 | D | | | | | 1 | 12 | | | | | | 1 | | 3 | | | | | 4 | 1 | 13 | R | R | R | | | | | 40 |
| *Utterbackia imbecillis* | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Subfamily Ambleminae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Amblema plicata* | | | | 2 | | R | R | | | | | | | | | | | | R | | R | | | | | 3 | R | | R | R | R | | | | | 5 |
| *Elliptio dilatata* | | | | | | | | | | | | | | | | | | | | | | | | | | R | | | | | | | | | | 0 |
| *Fusconaia flava* | 1 | 8 | 6 | 1 | 2 | 2 | R | | | 4 | 2 | | | | | | | | 7 | 2 | 1 | R | | | | 7 | D | 5 | 1 | D | 3 | | | | | 52 |
| *Pleurobema clava* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | R | | | | R | | 0 |
| *Quadrula pustulosa* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | R | | | | R | 0 |
| *Quadrula quadrula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | | 3 |
| *Tritogonia verrucosa* | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | R | 1 | | | | | | 2 |
| *Uniomerus tetralasmus* | | | R | | | | | | R | 1 | | R | 4 | R | | | | | | | | | | | | | | | | | | | | | | 9 |
| Subfamily Lampsilinae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Actinonaias ligamentina* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | R | 0 |
| *Lampsilis cardium* | | D | 2 | 16 | 11 | 12 | 19 | | 1 | 1 | | | | | | | R | 5 | 8 | 9 | 22 | | | | | 37 | 26 | 12 | 22 | 20 | 5 | | 5 | 5 | 2 | 240 |
| *Lampsilis siliquoidea* | 4 | 4 | 23 | 26 | 17 | 9 | 3 | D | 12 | 24 | 7 | 5 | | | 1 | | | | 12 | 4 | 8 | R | | | | 9 | 2 | 13 | R | R | | | | 1 | 1 | 185 |
| *Lampsilis teres* | | | D | 3 | 1 | 1 | | | | | | | | | | | | | | | R | | | | | 9 | D | 3 | 2 | 1 | 2 | | R | 3 | 2 | 27 |
| *Leptodea fragilis* | | | | 15 | 6 | 3 | 4 | | | | | | | | | | | | | | 3 | | | | | 15 | 8 | 33 | 6 | R | 2 | | | 4 | D | 99 |
| *Ligumia subrostrata* | | | | | | | | | | | | | | | | | | | | | | | | | | | R | | | R | R | | | R | | 0 |
| *Obovaria subrotunda* | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | 1 | | 2 |
| *Potamilus alatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | R | | | R | | | | 5 | 3 | 8 |
| *Potamilus ohiensis* | | | | | | | | | | | | | | | | | | | | | | | | | | | R | | | R | | | | | | 0 |
| *Ptychobranchus fasciolaris* | 2 | 1 | R | R | 1 | | R | | | 2 | | R | 1 | 1 | | | | | D | | | | D | R | | | | | | | | | | | | 8 |
| *Toxolasma parvus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 |
| *Truncilla donaciformis* | D | D | R | 2 | D | 6 | D | | 2 | 22 | 2 | 1 | | | | | | | D | R | R | R | | | | | R | | R | R | | | | | | 35 |
| No. of individuals | 19 | 14 | 37 | 68 | 42 | 35 | 26 | 0 | 19 | 56 | 11 | 7 | 17 | 1 | 1 | 1 | 0 | 7 | 37 | 15 | 43 | 0 | 0 | 0 | 0 | 87 | 37 | 79 | 34 | 22 | 12 | 0 | 6 | 24 | 8 | 765 |
| No. of live species | 7 | 4 | 7 | 8 | 8 | 7 | 3 | 0 | 4 | 8 | 3 | 3 | 3 | 1 | 1 | 1 | 0 | 2 | 7 | 3 | 7 | 0 | 0 | 0 | 0 | 10 | 4 | 6 | 4 | 3 | 4 | 0 | 2 | 9 | 4 | 20 |
| Total no. of species | 8 | 7 | 12 | 10 | 10 | 8 | 9 | 1 | 6 | 9 | 5 | 7 | 3 | 3 | 1 | 1 | 1 | 2 | 10 | 7 | 11 | 3 | 1 | 1 | 1 | 12 | 11 | 6 | 12 | 17 | 10 | 0 | 4 | 12 | 7 | 27 |
| Effort (person-hours) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 55 |

ic disturbances, the resultant effects of lowhead dams on the freshwater mussel assemblage include lowered species richness and altered abundances of certain species (Dean et al. 2002).

Several of the tributary streams of Brouilletts Creek are intermittent and do not appear to function as refugia for freshwater mussels, which is similar to data from other studies (e.g., Hoke 1997). Some of these streams appear to be "flashy" and have degraded, unstable habitats. Also, even though intermittent streams can offer diverse habitats (e.g., stable sand and gravel riffle area), periods of drought coupled with high temperatures create unsuitable habitat for freshwater mussels (Hoke 1997) by exposing portions of gravel bars and causing compaction of substrates through the drying of organic material in interstitial spaces (Tiemann et al. 2004). The unfavorable habitat might explain the absence of freshwater mussels in these areas.

## ACKNOWLEDGMENTS

R.E. Szafoni of the Illinois Department of Natural Resources (IL-DNR) provided the idea for this project. The IL-DNR partially funded the project through an Illinois Wildlife Preservation Fund Grant (#05-029), whereas other funding was provided by the Illinois Department of Transportation. The Indiana Department of Natural Resources (IN-DNR) issued an Indiana collecting permit. K.S. Cummings, C.A. Mayer, and C.A. Phillips of the INHS, J. Eggen, B. Fisher, and T. Briggs of the IN-DNR, and B.L. Tiemann assisted with fieldwork. F. Hutto (INHS) assisted in map creation. K.S. Cummings, J. Eggen, B. Fisher, G. Levin (INHS), R.E. Szafoni, D. Thomas (INHS), B.L. Tiemann, C. Warwick (INHS) and three anonymous reviewers provided constructive criticism and helpful suggestions.

## LITERATURE CITED

Call, R.E. 1896. Second contribution to a knowledge of Indiana Mollusca. Proceedings of the Indiana Academy of Science 1985:135–146.

Cummings, K.S. & C.A. Mayer. 1992. Field guide to freshwater mussels of the Midwest. Manual 5. Illinois Natural History Survey, Champaign. 194 pp.

Cummings, K.S. & J.M.K. Berlocher. 1990. The naiades or freshwater mussels (Bivalvia: Unionidae) of the Tippecanoe River, Indiana. Malacological Review 23(1):83–98.

Cummings, K.S. & C.A. Mayer. 1997. Distributional checklist and status of Illinois freshwater mussels (Mollusca: Unionacea). Pp. 129–145, *In* Conservation And Management Of Freshwater Mussels II: Initiatives For The Future. (K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo, eds). Proceedings of the UMRCC Symposium, 16–18 October 1995, St. Louis, Missouri. Upper Mississippi Conservation Committee, Rock Island, Illinois. 293 pp.

Cummings, K.S., C.A. Mayer & R.E. Szafoni. 1998. Endangered freshwater mussels (Mollusca: Unionidae) in the North Fork Vermilion River, Illinois with comments on the federally endangered clubshell, *Pleurobema clava* (Lamarck, 1819). Transactions of the Illinois State Academy of Science 91(1/2):90–102.

Dean, J., D. Edds, D. Gillette, J. Howard, S. Sherraden & J. Tiemann. 2002. Effects of lowhead dams on freshwater mussels in the Neosho River, Kansas. Transactions of the Kansas Academy of Science 105(3/4):232–240.

Hoke, E. 1997. The unionid mollusks of the upper Kansas basin of northwestern Kansas and southwestern Nebraska. Transactions of the Nebraska Academy of Sciences 24(1):35–62.

Hoke, E. 2004. The freshwater mussels (Mollusca: Bivalvia: Unionidae) of the Little Blue River drainage of northeastern Kansas and southeastern Nebraska. Transactions of the Nebraska Academy of Sciences 29(1):7–24.

Myers-Kinzie, M., S.P. Wente & A. Spacie. 2001. Occurrence and distribution of freshwater mussels in small streams of Tippecanoe County, Indiana. Proceedings of the Indiana Academy of Science 110:141–150.

Obermeyer, B.K., D.R. Edds, E.J. Miller & C.J Prophet. 1997. Range reductions of southeast Kansas unionids. Pp. 108–116, *In* Conservation And Management Of Freshwater Mussels II: Initiatives For The Future. Proceedings of the UMRCC Symposium, 16–18 October 1995. (K.S. Cummings, A.C. Buchanan, C.A. Mayer and T.J. Naimo, eds.). St. Louis, Missouri. Upper Mississippi Conservation Committee, Rock Island, Illinois. 293 pp.

Page, L.M., K.S. Cummings, C.A. Mayer, S.L. Post & M.E. Retzer. 1992. Biologically significant streams. An evaluation of the streams of Illinois based on aquatic biodiversity. Illinois Natural History Survey, Center for Biodiversity, Technical Report 1992(1), Champaign, Illinois. 485 pp.

Petzing, J.E., J.M. Mui, M.J. Dreslik, C.A. Phillips, D.B. Shepard, J.A. Crawford, A.R. Kuhns, M.J. Meyer, T.G. Anton, E.O. Moll, J.G. Palis & D. Mauger. 2002. Filling in the gaps I: New county records for amphibians and reptiles in Illinois. Herpetological Review 33(4):327–330.

Strayer, D.L. & D.R. Smith. 2003. A Guide To Sampling Freshwater Mussel Populations. American Fisheries Society, Monograph 8, Bethesda, Maryland. 103 pp.

Szafoni, R.E., K.S. Cummings & C.A. Mayer. 2000. Freshwater mussels (Mollusca: Unionidae) of the Middle Branch, North Fork Vermilion River, Illinois/Indiana. Transactions of the Illinois State Academy of Science 93(3):229–237.

Tiemann, J.S. 2004. Short-term effects of logging and bridge construction on habitat in two Kansas streams. Transactions of the Kansas Academy of Science 107(3/4):136–142.

Tiemann, J.S., D.P. Gillette, M.L. Wildhaber & D.R. Edds. 2004. Effects of lowhead dams on riffle-dwelling fishes and macroinvertebrates in a midwestern river. Transaction of the American Fisheries Society 133(4):705–717.

Turgeon, D.D., A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P.M. Mikkelsen, J.F. Quinn, Jr., C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, M.J. Sweeney, F.G. Thompson, M. Vecchione & J.D. Williams. 1998. Common And Scientific Names Of Aquatic Invertebrates From The United States And Canada: Mollusks. 2nd Edition. American Fisheries Society, Special Publication 26, Bethesda, Maryland. 526 pp.

Vaughn, C.C. 2003. The mussel fauna of the Glover River, Oklahoma. Proceedings of the Oklahoma Academy of Science 83(1):1–6.

Watters, G.T. 1994. An annotated bibliography of the reproduction and propagation of the Unionoidea (primarily of North America). Ohio Biological Survey Miscellaneous Contributions, Number 1. 158 pp.

Williams, J.D., M.L. Warren, K.S. Cummings, J.L. Harris & R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6–22.

*Manuscript received 15 January 2005, revised 11 April 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):43–54

# *ORCONECTES (PROCERICAMBARUS) THEAPHIONENSIS* (DECAPODA: CAMBARIDAE), THE SINKHOLE CRAYFISH, A NEW SPECIES OF CRAYFISH FROM SOUTHCENTRAL INDIANA

**Thomas P. Simon**[1], **Anne E. Timm**[2], and **Charles C. Morris**[1]: [1]Aquatic Research Center, Indiana Biological Survey, 6440 South Fairfax Road, Bloomington, Indiana 47401 USA; [2]Hoosier National Forest, U.S. Forest Service, 248 15th Street, Tell City, Indiana 47586 USA

**ABSTRACT.** A new species of crayfish ***Orconectes (Procericambarus) theaphionensis*** is described from southcentral Indiana in the karst areas of the Lost River and Blue Creek drainages. The species occurs both above and below the Orangeville Rise and in Stampers Creek. The species is distinguished from other recognized members of the subgenus by its strong carina, rostrum deflected, non-serrate mandible, broad carapace, presence of setae just posterior to the cervical groove and the anterior portion of the areola, and distinct chelae tubercle formula. The rostrum is concave dorsally, terminating in an upturned acumen, median carina strong. Rostral margins thickened; edges distally converging providing a slightly convex appearance; terminating in spines. The dactyl formula ranges from 0, 4–8, I, 3–4 (5), while the propodus formula is 0, i, 3–6, I, (2) 3–4. The central projection diverges from the mesial process and the central projection length to total length of pleopod (mean = 44.86%, range = 34.4–56.3%) is intermediate between *Orconectes cristavarius* and *O. putnami*. Of the recognized members of the subgenus *Procericambarus*, it is most similar to *Orconectes (P.) juvenilis*, which is found in southeastern Indiana and Kentucky. The new form can be differentiated from *O. (P.) juvenilis* by the presence of a strong median carina, the suborbital angle obsolete, and a divergent central and mesial projection that is greater than 35% central projection length to total length of pleopod.

**Keywords:** Taxonomy, *Procericambarus*, Cambaridae

Taylor (2000) diagnosed the *Orconectes juvenilis* complex and provided empirical data that elucidated the taxonomic status of members of this group. The group belongs to the crayfish subgenus *Procericambarus* (Fitzpatrick 1987), which possesses a strong angular shoulder on the cephalic surface at the base of the form I male pleopod's central projection, the central projection accounting for at least 35% of the total pleopod length. The *Orconectes juvenilis* complex as described by Taylor (2000) includes six species. Hobbs (1972) and Bouchard (1976) included in the complex, *Orconectes juvenilis* (Hagen 1870), *Orconectes spinosus* (Bundy 1877), and *Orconectes putnami* (Faxon 1884), while Taylor (2000) added *Orconectes rusticus* (Girard 1852), *Orconectes ronaldi* Taylor 2000, and *Orconectes cristavarius* Taylor 2000. All six species are native in the unglaciated Interior Plateau region of Kentucky, Indiana, West Virginia, and Ohio, and inhabit rocky streams and rivers.

During studies of the crayfish fauna of Indiana, the senior author has found several new crayfish species of the *Procericambarus* subgenus. The recent taxonomic diagnosis by Taylor (2000) has provided an opportunity to reduce the complexity of this group and validate other closely related taxa. Faxon (1885) recognized extreme variation in character state combinations of species later assigned to *Procericambarus*; while Hagen (1870), Ortmann (1931), and Faxon (1884) recognized varieties of *O. rusticus* and various combinations of synonymized species within *O. juvenilis*.

Here we examine the morphological variation within an undescribed member of *Procericambarus* occurring in Indiana. As the southern unglaciated portions of Indiana are analyzed, character states necessary for distinguishing species boundaries will likely provide information necessary for description of additional new species in the *Procericambarus* complex.

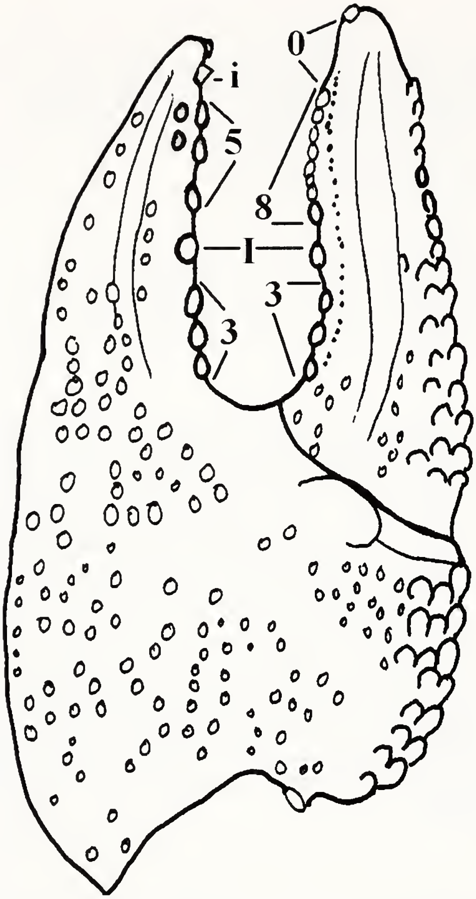


Figure 1.—Left chelae showing an example of the dactyl and propodus formula. *Note:* Propodus tubercles are in two rows; dactyl tubercle formula: 0, 8, I, 3; propodus tubercle formula: i, 5, (3 + 2), I, 3.

## METHODS

Specimen measurements follow Taylor (2000), with the exception of a formula we develop for describing the number of tubercles on the opposable margins of the dactyl and propodus. This formula does not include the corneous distal tip of either the dactyl or propodus. The formula is derived by counting the number of denticles on distal edge of the dactyl and propodus (see example in Fig. 1). Generally, if this area is blade-like then a zero is noted. The first set of denticles is usually a series of very small tubercles that slightly increase in size. These denticles can be in several rows on the dactyl. The denticles are reported as Arabic numbers. A small triangular, corneous canine-like tooth is often the first denticle found on the propodus. We denote this triangular tooth with a lower case Roman numeral series. Generally, the mid-point of both the dactyl and propodus has a large, spherical to oval, tubercle that is the largest in the series. We denote this tubercle by an upper case Roman numeral. Finally, the tubercles that are proximal to the palm are denoted by Arabic numbers. Using this convention provides a methodology to differentiate between corneous, triangular tubercles, denticles, and large tubercles. We have found these tubercle characters to be consistent and diagnostic of crayfish species in both *Orconectes* and *Cambarus* genera (T.P. Simon unpubl. data).

### ***Orconectes (Procericambarus) theaphionensis*** new species
Sinkhole Crayfish
Figs. 2, 3–12; Table 1

*Cambarus rusticus.*—Girard 1852:8; Faxon 1885: 108, pl. 9: figs. 8, 8′, 8a, 8a′ [in part]; Hay 1891: 149 [in part].

*Cambarus (Faxonius) rusticus.*—Ortmann 1905: 112 [in part]; Ortmann 1931:82 [in part]; Eberly 1955:182 [in part].

*Faxonius (Faxonius) rusticus.*—Creaser 1933:21 [in part].

*Orconectus rusticus.*—Dubois & Sharma 1977:27 [in part].

*Procambarus rusticus.*—Huner 1978:4 [in part].

*Orconectes (Procericambarus) rusticus.*—Hobbs 1972:92 figs. 74c, 75b,d; 1974:40, fig. 136 [in part]; Fitzpatrick 1987:58 [in part]; Hobbs 1989: 49 [in part]; Page & Mottesi 1995:109 [in part]; Taylor 2000:138 [distribution map]; Simon 2001: 107 [in part].

**Etymology.**—The species is named for the sulphur springs that are prevalent in the study area. Greek *theaphion*—of sulphur and brimestone. The vernacular name, sinkhole crayfish, refers to the Lost River watershed, perhaps among the largest cave systems in Indiana and North America.

**Diagnosis.**—Body and eyes pigmented. Rostrum concave dorsally, terminating in upturned acumen, median carina strong. Rostral margins thickened; edges distally converging providing a slightly convex appearance; terminating in lateral spines. Areola 29.0–40.2% ($\bar{x}$ = 34.2, $n$ = 100, SD = 1.63) of total length of carapace, narrowest part at midpoint, 12.4–39.4% ($\bar{x}$ = 21.6, $n$ = 100, SD = 5.11) times as long as wide with 3–5 punctations (mode

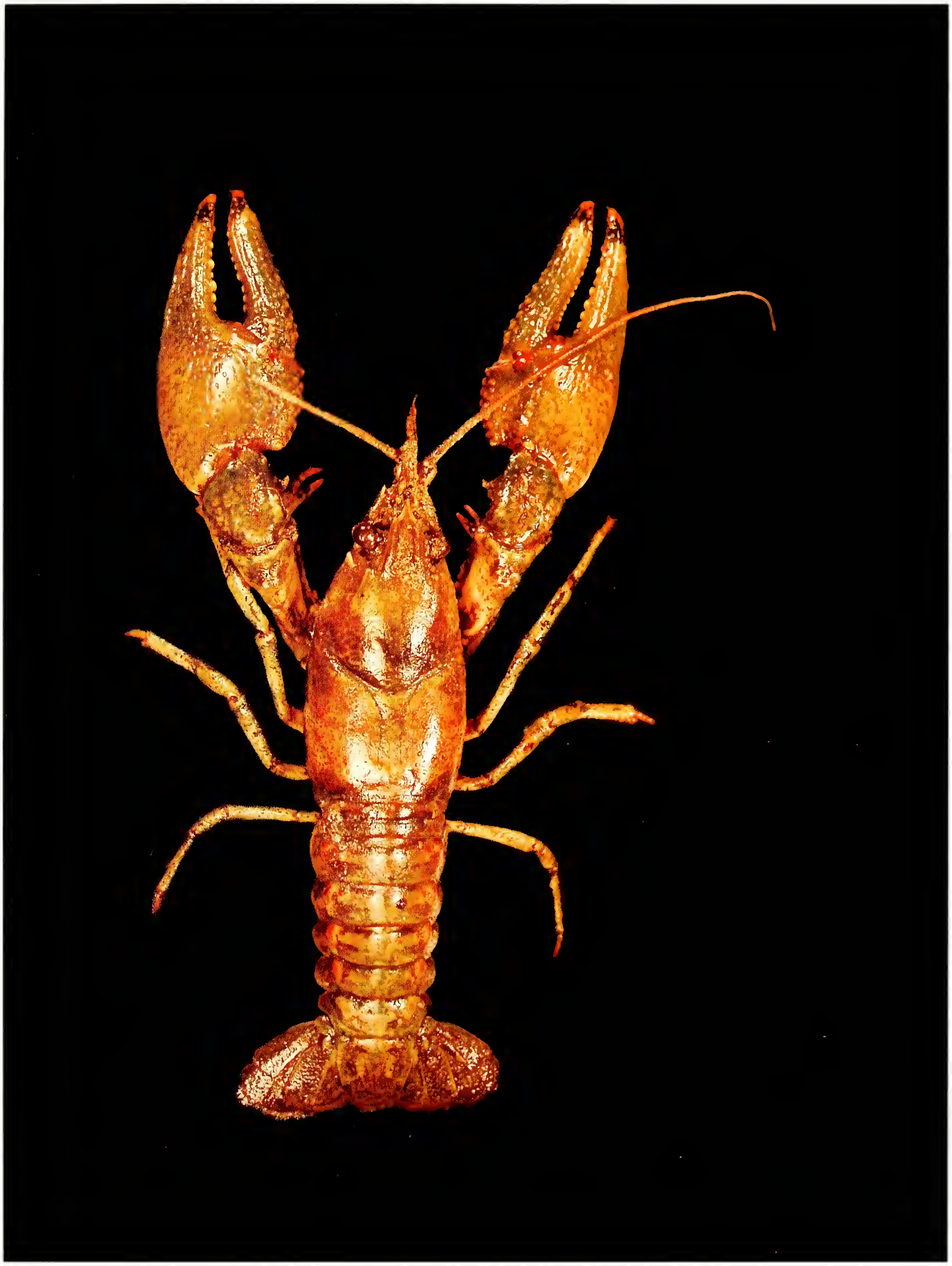
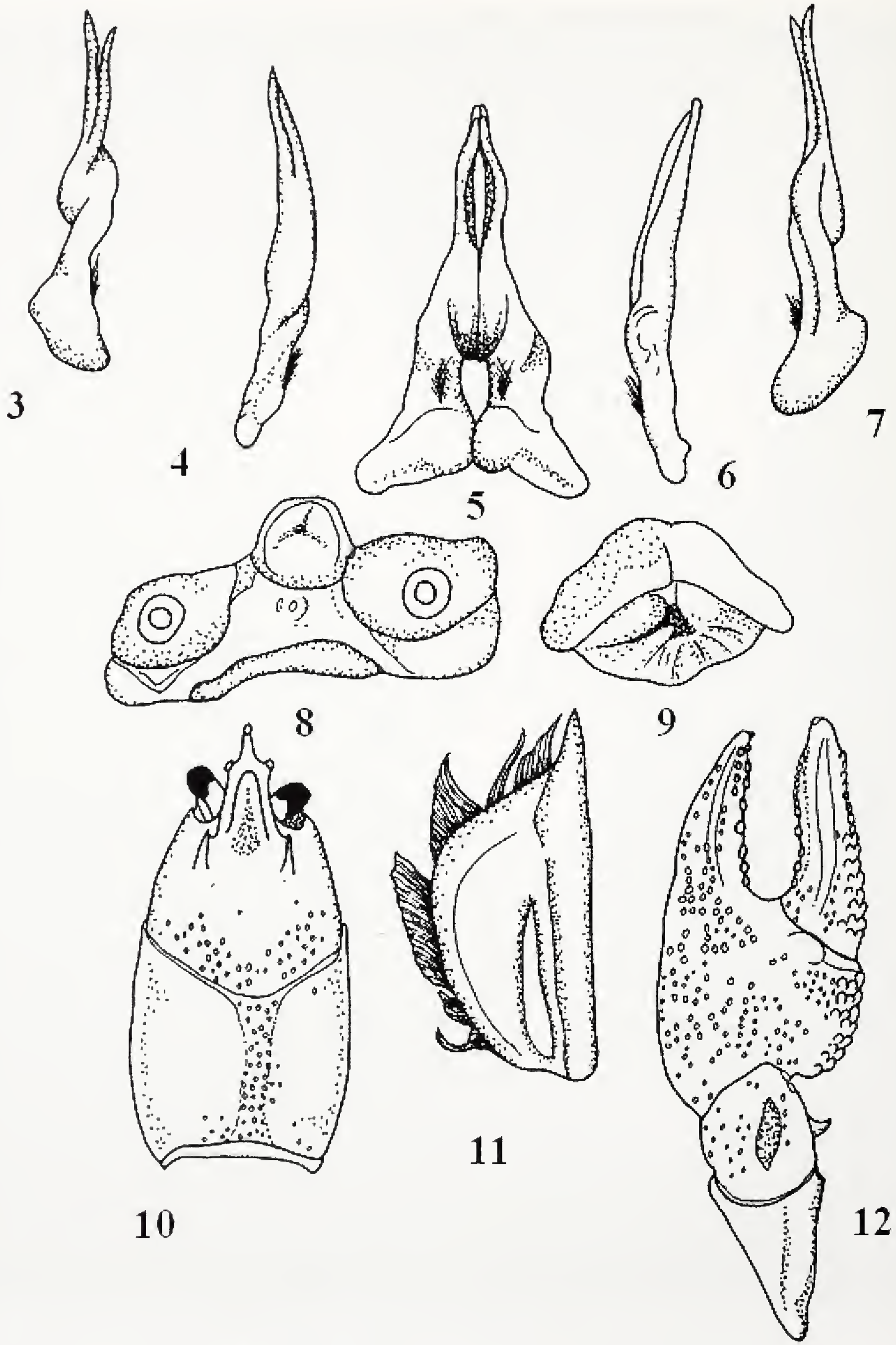


Figure 2.—***Orconectes theaphionensis*** new species. Total length of carapace is 33.2 mm. Holotype form I male, Half Moon Springs at Indiana County Road 200 E bridge, 2.6 km W of Chambersburg, Paoli Township, Orange County, Indiana (USNM 1075206).

= 4, *n* = 100, SD = 0.58). One corneous hepatic spine on each side of carapace. Postorbital ridges well-developed, terminating in slightly upturned corneous spines. Suborbital angle obsolete. Antennal scale broadest at midlength, thickened lateral margin terminating in large corneous spine. Ischia of third pereiopods of males with hooks; hooks over-



Figures 3–12.—***Orconectes theaphionensis*** new species. 3. Mesial view of first pleopod of form I male; 4. Mesial view of first pleopod of form II male; 5. Caudal view of first pleopods of form I male; 6. Lateral view of first pleopod of form I male; 7. Lateral view of first pleopod of form II male; 8. Epistomal zygoma; 9. Annulus ventralis; 10. Dorsal view of carapace; 11. Dorsal view of right antennal scale; 12. Dorsal view of left chela. 3, 6, 8, 10, 12 of holotype (USNM 1075206); 5. Paratype (INBS 841); 4,7. Morphotype (USNM 1075208); 9,11, Allotype (USNM 1075207).

Table 1.—Measurements (mm) of ***Orconectes theaphionensis*** new species.

| | Holotype | Allotype | Morphotype |
|---|---|---|---|
| Carapace: | | | |
| Total length | 33.2 | 36.4 | 28.3 |
| Postorbital length | 26.3 | 27.5 | 20.9 |
| Width | 16.3 | 18.3 | 14.4 |
| Height | 15.4 | 18.1 | 11.6 |
| Areola: | | | |
| Width | 2.4 | 3.1 | 1.5 |
| Length | 11.5 | 11.7 | 9.6 |
| Rostrum: | | | |
| Width | 3.5 | 4.1 | 3.0 |
| Length | 6.9 | 9.0 | 7.4 |
| Chela, right: | | | |
| Length, mesial margin of palm | 10.1 | 7.3 | 7.0 |
| Palm width | 16.1 | 11.5 | 8.6 |
| Length, lateral margin | 35.9 | 24.6 | 21.9 |
| Dactyl length | 17.8 | 11.4 | 9.4 |
| Abdomen: | | | |
| Width | 14.4 | 17.2 | 11.9 |
| Length | 33.0 | 37.3 | 29.6 |

reaching basioischial articulation in form I males only. Chela with 2–3 rows of tubercles along mesial margin of palm, usually 6–10 tubercles in mesial most row, 4–8 in dorsomesial row, and occasionally present are a proximalmesial row of 3–9 weakly developed tubercles running to knob at base of dactyl; small tufts of setae on mesial margin of palm, dorsomesial and dorsolateral surfaces, and fingers; dorsal surfaces of fingers with well-developed longitudinal ridges. First pleopods of form I male symmetrical, extending to just past anterior edge of bases of second pereiopods when abdomen flexed. First pleopod of form I male with well-developed shoulder on cephalic surface at base of central projection; without strong 90° central projection corneous, constituting 34.4–56.3% ($\bar{x}$ = 44.86%, *n* = 50, SD = 5.47) of total length of first pleopod, straight and tapering to a pointed tip; mesial process non-corneous and straight, distal end dorsally compressed and tapering to acute tip (see Variation), slightly subequal in length to central projection. First pleopod of form II male noncorneous, extending to anterior edge of bases of second pereiopods when abdomen flexed; central projection straight, mesial process divergent from central projection, straight and subequal in length; both elements tapering to rounded tips. Annulus ventralus immovable, subcircular; cephalic half with wide median trough and two caudally-directed protuberances overhanging centrally located fossa; sinuate sinus running from center of fossa to caudal edge.

**Description of holotypic male, form I.**—Body slightly depressed dorsoventrally, carapace wider than abdomen (16.3 and 14.4 mm, respectively). Greatest width of carapace larger than height at caudodorsal margin of cervical groove (16.3 and 11.5 mm, respectively). Postorbital carapace length (26.3 mm) 79.2% of length of carapace. Areola 20.9 times longer (11.5 mm) than wide (2.4 mm) with four punctations across narrowest part; length of areola 34.5% of total length of carapace. Rostrum densely covered with punctations, excavated, strong median carina present; margins thickened, distal halves straight and slightly converging, terminating in rounded corneous spines, proximal halves slightly convex. Acumen terminating in upturned corneous spine and reaching just distal of midpoint of antennular peduncle. Postorbital ridges well-developed, terminating in slightly upturned corneous spines. Suborbital angle obsolete. Cervical spines corneous; branchiostegal areas of carapace smooth to slightly granular, dorsal surface with scattered punctations. Setae present posterior to the cervical groove and anterior area of the areola.

Carapace length nearly equal in length to abdomen (33.2 and 33.0 mm, respectively). Cephalic section of telson with two immovable spines in each caudolateral corner extending over exopodite. Caudal margin of cephalic section of exopodite with numerous fixed spines (21) and one large movable spine in caudolateral corner. Cephalic and caudal sections of exopodite with prominent median ridge. Lateral margin of endopodite terminating in spine; endopodite with prominent median ridge terminating in premarginal spine. Dorsal surface of telson and uropods setiferous. Antennal scale broadest at midlength, thickened lateral margin terminating in large corneous spine. Right antennal scale 7.02 mm long, 2.43 mm wide.

Mesial surface of palm of left chelae with three rows of tubercles, eight tubercles in mesial most row, seven tubercles in dorsomesial row, and three small widely interspersed tubercles lateral to dorsomesial row, six basiodactyl punctations form a weak row running to knob at base of dactyl. Mesial and lateral surfaces of chela covered with numerous setiferous punctations; ventral surface with scattered punctations. Dorsal surface of finger of propodus with submedian longitudinal ridges flanked by setiferous punctations; basal half of opposable margin with four small tubercles, a large prominent tubercle near midlength, five well-developed distal tubercles, and a small, triangular, corneous tubercle near distal edge (propodus tubercle formula: 0, 8, I, 4). Dorsal and ventral surfaces of dactyl with submedian longitudinal ridges flanked by setiferous punctations; basal half of opposable margin with four well-developed tubercles, a large prominent tubercle at midlength, and eight distal tubercles in two interdigitated row (dactyl tubercle formula: 0, i, 5, I, 4). Finger of propodus and dactyl with rounded subterminal corneous tip.

Carpus with deep oblique furrow dorsally; mesial margin with a single large corneous procurved spine at midlength and three small corneous spines along distomesial margin; ventral surface with a single corneous spine just mesial to mid-length of distal margin, distoventrolateral corner enlarged and globular with a single small corneous spine overhanging chelae. Dorsodistal surface of merus with three corneous spines; ventral surface with two large corneous spines and a single tubercle at midlength of ventrolateral margin and lateral to mesial row of seven spines, some corneous; row terminating in large corneous spine; small tubercle at distolateral corner. Ischium with a single tubercle just proximal to midlength of mesial margin and a single noncorneous spine on distal end of mesial margin.

Hook on ischium of third pereiopod only; hook simple, overreaching basioischial articulation and opposed by large rounded tubercle on basis. First pleopod as in Diagnosis above, central projection constituting 47.7% of total length of first pleopod.

**Description of allotypic female.**—Differing from holotype as follows. Areola constituting 32.1% of length of carapace and 3.8 times longer than wide. Postorbital carapace length 75.4% of length of carapace. Acumen with upturned corneous spine at distal tip. Mesial row of tubercles along palm of left chela with eight tubercles, dorsomesial row with seven, and distal dorsomesial row with three tubercles. Propodus with tuft of long setae at base of finger of opposable propodus with four well-developed tubercles proximal to palm, a prominent large tubercle at midlength, and five small distal tubercles in two interdigitated rows, with a single small, corneous, triangular, hooked tubercle at distal edge (propodus tubercle formula: 0, i, 5, I, 4). Opposable margin of dactyl with four well-developed tubercles, a single prominent tubercle at midlength, and five distal tubercles (dactyl tubercle formula: 0, 5, I, 4). Ventral surface of left merus with two corneous spines at midlength and lateral row of tubercles along mesial margin.

Sternum between third and fourth pereipods narrowly V-shaped. Postannular sclerite as wide as annulus ventralis. Annulus ventralis described in Diagnosis. First pleopods uniramous, barely reaching caudal margin of annulus when abdomen flexed.

**Description of morphotypic male, form II.**—Differing from holotype as follows. Areola constituting 33.9% of length of carapace and 6.4 times longer than wide. Postorbital carapace length 73.7% of length of carapace. Acumen with upturned corneous spine at distal tip. Mesial row of tubercles along palm of left chela with eight tubercles, dorsomesial row with five tubercles, and distal dorsomesial row with five tubercles. Dorsodistal surface of left merus with two corneous spines. Ventral surface of left merus with a single corneous spine and another single tubercle at midlength and lateral to row of tubercles along mesial margin.

Hook on ischium of third pereiopod not overreaching basioischial articulation. First pleopod without well-developed divergent mesial projection, instead blunt and blade-shaped, as described in Diagnosis.

**Size.**—Largest specimen examined 39.2 mm total carapace length (CL) form I male. Females (*n* = 25) ranging in size from 22.8–36.4 mm CL. Form I males (*n* = 50) ranging from 21.4–39.2 mm CL. Form II males (*n* = 25) ranging in size from 19.4–36.5 mm CL.

**Color.**—Dorsal and lateral surfaces of cephalothorax, pereiopods, and tail fan light brown to olive green. Dorsum with one large laterally elongate dark brown patch just anterior to areola. Cephalothorax with dark brown dorsolateral U-shaped saddle connected at caudal margin and extending to just posterior of midlength of lateral surfaces. Dorsal surfaces of abdominal segments 1–5 with dark brown patches, patches forming solid dark brown bar running from posterior edge of carapace to fifth abdominal segment when abdomen extended. Lateral surfaces of abdominal segments light orange, followed laterally by dark brown patches at edges. Dorsal and lateral surfaces of chelae, carpus, and merus olive green; dorsal surface of chelae covered with small dark flecks. Fingers of chelae with orange tips, followed proximally by wide black bands. Ventral surfaces of chelae, cephalothorax, and abdomen cream to white.

**Type locality.**—Half Moon Springs at bridge at Indiana County Road 200 E, 2.57 km W of Chambersburg, Paoli Township, Orange County, Indiana; 38.5207348 °N, 86.4229192 °W. The holotype was collected from a riffle on limestone bedrock in mid-channel, about 20 m upstream of the bridge. The allotype, morphotype, and paratypes were collected from cobble and slab bolder riffle habitats in close proximity to the holotype collection. At the time of collection, Half Moon Spring was 2.7 m wide with an average depth of 0.4 m. Substrate at the type locality was limestone bedrock with slab cobble and boulders. The stream is located in Hoosier National Forest and land use adjacent in the stream channel is pasture and forest.

**Disposition of types.**—The holotype, allotype, and morphotype are deposited at the National Museum of Natural History, Smithsonian Institution, Washington, D.C. (USNM 1075206, USNM 1075207, and USNM 1075208, respectively). Paratypes consisting of 12♂I, 30♂II, 2juv♂; 42♀, 7juv♀ (INBS 841) are deposited at the Indiana Biological Survey, Aquatic Research Center, Crustacean Collection, Bloomington, Indiana; paratypes 1♂I, 1♂II, and 1♀ (OSUMC 5972) are deposited at the Ohio State University Museum of Biodiversity, Columbus, Ohio; and paratypes 1♂I, 1♂II, and 1♀ (INHS 9552) are deposited at the Illinois Natural History Survey Crustacean Collection, Champaign, Illinois.

**Range.**—***Orconectes theaphionensis*** new species, is found in the Lost River drainage, above and below the Orangeville Rise, including Stampers Creek and other sinkholes, and adjacent Blue Creek (East Fork White River drainage) in south central Indiana (Fig. 13). The Lost River originates in eastern Orange County flowing northeast for about 57.3 km before emptying into the East Fork White River. Stampers Creek is a disjunct stream channel that is connected to the Lost River through sinkhole connections. Blue Creek occurs directly west of the Lost River entering the East Fork White River near Shoals. Both watersheds drain interbedded limestones, sandstones, and shale deposits of middle Pennsylvanian age. The species may be present in Blue River (Harrison County; C.A. Taylor pers. commun.) and Indian Creek (Harrison County; TPS, unpubl. data); however, further genetic analysis of these two drainage forms may be necessary since our morphometric and pigmentation data suggest that they are new species.

A total of 1354 specimens has been examined from 42 locations in Indiana. Museum collection numbers and counties for these sites are listed in the Material Examined section, below.

**Habitat and life-history notes.**—*Orconectes theaphionensis* new species, occurs in creeks and small rivers with substrates of limestone bedrock, slab boulder and cobble rubble, and large gravel. The species is most commonly encountered along rock substrates

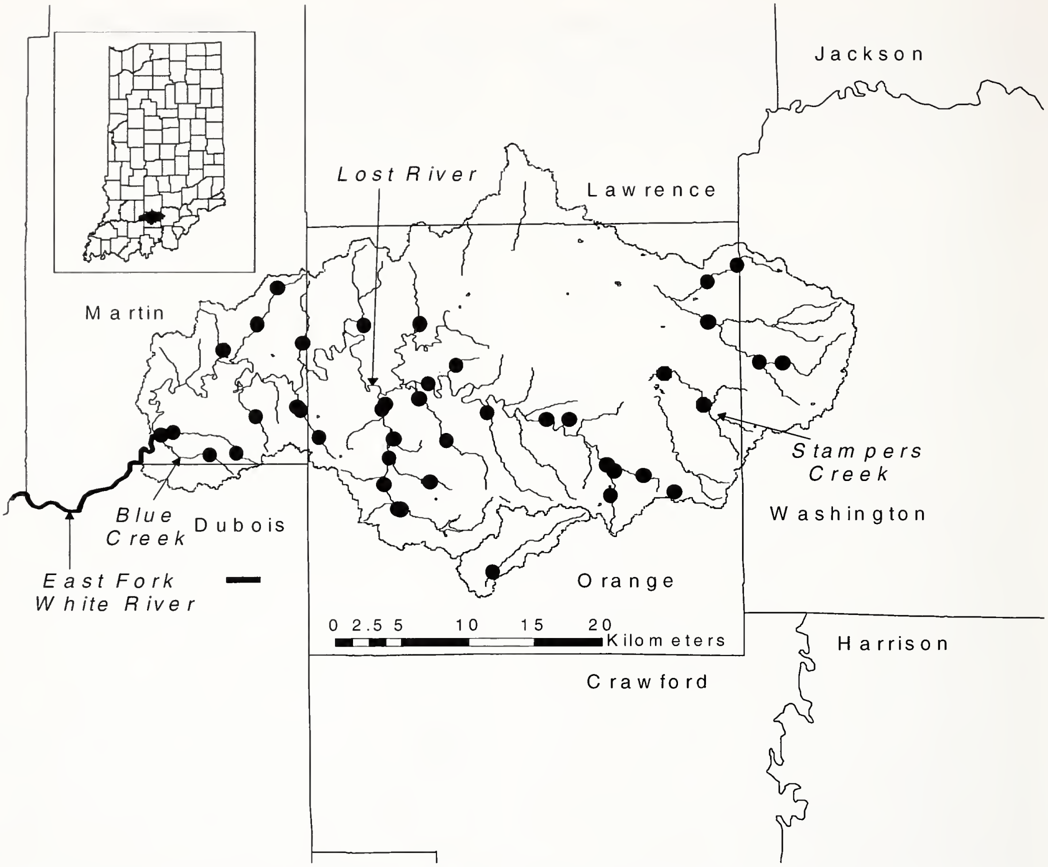


Figure 13.—Distribution of ***Orconectes theaphionensis*** new species, throughout its known range in the Lost River, Stampers Creek, and Blue Creek drainages, Indiana.

Table 2.—Seasonal data showing by month numbers of individuals of each sex including sex ratios for ***Orconectes (Procericambarus) theaphionensis***, new species. [a] = Female with eggs collected during this month, [b] = Female with eggs and young collected during this month.

| | Male I | Male II | Females | Sex ratio |
|---|---|---|---|---|
| February | 0 | 0 | 4 | — |
| March | 8 | 2 | 16[a] | 1/1.6 |
| April | 3 | 0 | 18 | 0.17/1 |
| May | 138 | 46 | 214[b] | 1/2.5 |
| June | 44 | 178 | 334 | 1/1.5 |
| July | 12 | 31 | 50 | 1/1.16 |
| August | 4 | 12 | 23 | 1/1.4 |
| September | 55 | 43 | 142 | 1/1.4 |
| October | 118 | 23 | 211 | 1/1.5 |

in shallow riffle areas or among slowly-flowing runs.

Form I males have been collected in all months sampled March-October, and we have not sampled during November to January (Table 2). No males were collected during February. Juveniles have been collected in June and July. Ovigerous females were collected on 25 March 1999 and 18 May 2004. One 26.7 mm CL female was carrying 113 eggs that averaged 1.20 mm in diameter, whereas a 28.9 mm CL individual carried 121 eggs that averaged 1.18 mm in diameter.

**Crayfish associates.**—The following species were collected from habitat containing *O. theaphionensis* new species: *Cambarus (Erebicambarus) tenebrosus* Hay 1902 (formerly *Cambarus (Erebicambarus) laevis* Faxon 1914); and *Orconectes (Trisellescens) immunis* (Hagen 1870); *Cambarus (Lacunicambarus)* sp. "B"; *Cambarus (Lacunicambarus)* sp. "C"; *Cambarus (Tubericambarus)* sp. "A."

**Variation.**—Ontogenetic variation is observed in *Orconectes theaphionensis* new species, none of which shows any geographic patterns of distribution. Weakly developed granular tubercles are occasionally apparent on the branchiostegal area. The pleopod in most form II male individuals has a mesial process that tapers to a sharply pointed distal tip, but in some specimens the distal one-third is spatulate due to a dorsoventral compression of the process. The dactyl and propodus formulas show distinct patterns, but the largest individuals have slightly more tubercles, such as the holotype. The dactyl formula range is 4–8 (usually in two rows), I, 3–4 (rarely 5), while the propodus formula is, 0, i, 3–6, I, (rarely 2) 3–4. Some increase in carapace width was observed in populations from Sulphur Creek; however, we view this variability as an ecomorph due to the prevalent cool temperatures (< 17 °C year round). In many smaller individuals, the entire length of the rostral margin is straight.

**Comparisons.**—*Orconectes theaphionensis* new species, differs from all other members of the genus *Orconectes* by possessing a unique combination of form I male pleopod, mandible, rostral carina, and chelae characters (Table 3). Only *O. theaphionensis* has a slightly caudally-divergent central and mesial projection in form I males. The central projection to total length of pleopod (mean = 44.86%, range = 34.4–56.3%) is intermediate between *Orconectes cristavarius* and *O. putnami* (Taylor 2000). In addition to *O. theaphionensis*, within the subgenus *Procericambarus*, only *O. luteus* (Creaser 1933) has a deflected central projection, but *O. theaphionensis* lacks a deflected mesial projection as *O. luteus*. The mandible is unserrated, and the chelae has three rows of mesial tubercles. The new form differs from *O. juvenilis* and *O. rusticus* by the presence of the strong median carina, suborbital angle obsolete, a divergent central and mesial projection that is greater than 35% central projection length to total length of pleopod.

**Relationships.**—The form I male pleopod of *O. theaphionensis* is most similar in length and general shape to members of the subgenus *Procericambarus*, and we assign *O. theaphionensis* to that subgenus. Until either molec-

Table 3.—Comparison of characters diagnostic for ***Orconectes (Procericambarus) theaphionensis*** new species for differentiation from other *Procericambarus* species. TLP = total length of pleopod, mean value reported with range of values in parentheses. *n* = number of individuals examined for each species.

| Characters | *Orconectes theaphionensis* (*n* = 100) | *Orconectes juvenilis* (*n* = 134) | *Orconectes rusticus* (*n* = 68) | *Orconectes cristavarius* (*n* = 180) | *Orconectes putnami* (*n* = 43) | *Orconectes ronaldi* (*n* = 81) |
|---|---|---|---|---|---|---|
| Carina | strong | absent | absent | present | absent | absent |
| Mandible incisor | non-serrate | non-serrate | non-serrate | serrate | serrate | serrate |
| Cervical groove setae | present | absent | absent | absent | absent | absent |
| Mesial palm tubercles | 2–3 rows | 2 rows | 2 rows | 2 rows | 2 rows | 2 rows |
| mesial tubercles | 6–10 | 6–11 | 6–11 | 7–11 | 9–10 | 7–9 |
| dorsomesial | 4–8 | 7–11 | 7–12 | 5–10 | 8–10 | 6–8 |
| proximal mesial | 3–9 | | | | | |
| Central projection length: TLP | 44.9%<br>(34.4–56.3%) | 48.3%<br>(41.2–52.3%) | 41.7%<br>(35.7–46.5%) | 47.0%<br>(40.0–52.0%) | 53.1%<br>(48.4–57.0%) | 45.0%<br>(41.0–49.0%) |
| Chelae tubercle formula | | | | | | |
| dactyl | 0, 4–8, I, 3–4 (5) | 0, 4–5, III, 4 | 0, 10–16 | 0, 1–2, I, 4–5 | 0, 7–8, III–IV, 3–4 | 0, 3–4, I, 5–6 |
| propodus | 0, i, 3–6, I, (2) 3–4 | 0–2, i, 5, I–III, 2 | 8–13, i, 3–4, I, 2–4 | 0, _, 1–2, I, 3–4 | 3–4, i, 3–4, III–IV, 2 | 0, i, 3–4, I, 5–6 |

ular or morphological data from *O. theaphionensis* can be included in a phylogenetic analysis, we refrain from inferring the position of *O. theaphionensis* within the subgenus.

**Material examined.**—Number, sex, and form of specimens examined are in parentheses. Asterisks (*) denote samples from which specimens were obtained for the statistical analyses; females and form II males were limited to 25 specimens. Data for monthly sex ratios (Table 2) was from the data below and from monthly repeat visits to the type locality. Form I male is indicated by MI, MII = form II male by MII, F = female, and juv = juvenile. CR = County Road, SR = State Road, N = North, S = South, E = East, W = West and combinations. Collector(s) names are abbreviated after first use. INBS = Indiana Biological Survey Crustacean Collection.

### *Orconectes theaphionensis*

**INDIANA:** *Martin County:* Tributary to Big Creek, fire road, 4.8 km N Natchez, Halbert Twp, 38.64704 N, 86.70642 W, (Thomas P. Simon, Erin R. Lawrence, Stephanie L. Worden, Jake L. Burskey), 17 May 2004, (* 3 MI, 6 MII, 20 F), INBS 835. Big Creek, US 150 bridge, 1.3 km W Natchez, Halbert Twp, 38.61883 N, 86.72565 W, (TPS, ERL, SLW, JLB), 17 May 2004 (* 2 MI), INBS 836. Unnamed tributary Lost River, 1.0 km N on CR 191, 1.8 km N Roland, Halbert Twp, 38.60868 N, 86.68498 W, (TPS, SLW), 1 September 2004, (* 1 MI, 6 MII, 3 F), INBS 859. Unnamed tributary Lost River, CR 198 bridge, 3.7 km S Roland, Lost River Twp, 38.56330 N, 86.68717 W, (TPS), 12 July 2004, (* 2 MII, 8 F, 65 juv), INBS 861. Unnamed tributary Lost River, CR 4 bridge, 3.5 km S Roland, Lost River Twp, 38.56534 N, 86.68970 W, (TPS), 12 July 2004, (5 juv), INBS 862. Unnamed tributary Lost River, CR 195 bridge, 1.0 km NNW Natchez, Halbert Twp, 38.62170 N, 86.72446 W, (TPS), 1 July 2004, (5 MI, 4 MII, 11 F), INBS 863. Blue Creek, CR 900 E bridge, 3.5 km SE Rusk, Lost River Twp, 38.53398 N, 86.74278 W, (TPS), 14 July 2004, (11 juv), INBS 864. Blue Creek, CR 5 bridge, 0.2 km N Yenne, Lost River Twp, 38.54859 N, 86.79698 W, (TPS, JLB), 12 July 2004, (6 MII, 2 F, 41 juv), INBS 865. Blue Creek, CR 37 bridge, 1.3 km W Yenne, Lost River Twp, 38.54683 N, 86.80775 W, (TPS, SLW), 1 September 2004, (11 *I, 36 MII, 37 F), INBS 866. Unnamed tributary Lost River, CR 177 bridge, 2.7 km SE Yenne, Lost River Twp, 38.53297 N, 86.76574 W, (TPS), 14 July 2004, (3 juv), INBS 867. Qualkenbush Spring, CR 7, 3.5 km WSW Natchez, Halbert Twp, 38.60410 N, 86.75406 W, (TPS, JLB, ERL, SLW), 1 July 2004, (*2 MI, *3 MII, *4 F), INBS 868. *Orange County:* Carters Creek, CR 650 E bridge, 3.2 km SE Leipsic, North East Twp, 38.64843 N, 86.33554 W, (TPS, Brant E. Fisher, Katherine Gremillion-Smith), 18 March 1999, (12 MI, 6 MII, 5 F), INBS 828. Lost River, CR 650 E bridge, 3.2 km N Bromer, North East Twp, 38.62109 N, 86.33545 W, (TPS, BEF, KGS), 18 March 1999, (19 MI, 3 MII, 12 F), INBS 829. Carters Creek, Sutter Lane bridge, 4.8 km ESE Leipsic, North East Twp, 38.65931 N, 86.30991 W, (TPS, BEF, KGS), 18 March 1999, (7 MI, 1 MII, 10 F), INBS 830. Tributary to Halfmoon Springs, US 150 bridge, 3.2 km SE Paoli, Paoli Twp, 38.54503 N, 86.44936 W, (TPS, ERL), 16 June 2004, (1 MI, 1 F, 12 juv), INBS 833. Tributary to Halfmoon Springs, US 150 bridge, 0.3 km NW Chambersburg, Paoli Twp, 38.51769 N, 86.39197 W, (TPS, ERL, SLW, JLB), 17 June 2004, (*1 MI, 1 MII, 4 F), INBS 834. Stampers Creek, SR 56 bridge, 0.5 km SE Millersburg, Stampers Creek Twp, 38.55731 N, 86.33351 W, (TPS), 21 June 2004, (2F), INBS 837. Stampers Creek, CR 500 E bridge, 2.6 km NE Millersburg, Stampers Creek Twp, 38.58821 N, 86.36446 W, (TPS, ERL, SLW, JLB), 21 June 2004, (19 MII, 29 F, 12 juv), INBS 838. Lick Creek, CR 350 S bridge, 2.6 km WSW Chambersburg, Paoli Twp, 38.50657 N, 86.41743 W, (TPS, SLW), 13 September 2004, (*1 MI, 11 MII, 9 F, 3 juv), INBS 839. Halfmoon Springs, CR 200 E bridge, 5.2 km W Chambersburg, Paoli Twp, 38.52073 N, 86.42292 W, (TPS), 21 June 2004, (29 MII, 81 F, 31 juv), INBS 840. Unnamed tributary Lick Creek, Spring Mill Road bridge, 2.3 km WNW Chambersburg, Paoli Twp, 38.52488 N, 86.41997 W, (TPS, SLW), 13 September 2004, (*16 MI, *34 MII, *46 F, 9 juv), INBS 841. Willow Creek, CR 125 W, 4.8 km SSW Paoli, Paoli Twp, 38.50398 N, 86.45630 W, (TPS, SLW), 13 September 2004, (16 MI, 2 MII, 10 F), INBS 842. Lick Creek, S Elm Street bridge, 1.9 km W Paoli, Paoli Twp, 38.55585 N, 86.47484 W, (TPS), 24 June 2004, (2 MI, 18 MII, 22 F, 6 juv), INBS 843. Log Creek, Log Creek Road, 4.8 km SW Paoli, Paoli Twp, 38.54277 N, 86.52128 W, (TPS), 24 June 2004, (4 juv), INBS 844. Log Creek, Log Creek Road, 4.5 km W Paoli, Paoli Twp, 38.56097 N, 86.52625 W, (TPS, Anne E. Timm, JLB, ERL, SLW), 30 June 2004, (*13 MI, *26 MII, *53 F, 47 juv), INBS 845. Unnamed tributary Lick Creek, CR 500 W bridge, 6.1 mi NE West Baden Springs, Orangeville Twp, 38.59293 N, 86.55263 W, (TPS), 24 June 2004, (*10 MI, *21 MII, *22 F, 2 juv), INBS 846. Lick Creek, US 150 bridge, 2.7 km NE West Baden Springs, French Lick Twp, 38.5061 N, 86.57680 W, (TPS, SLW), 13 September 2004, (1 MI, 2 MII, 1 F), INBS 847. Upper Sulphur Creek, CR 100 S bridge, 4.0 km E French Lick, French Lick Twp, 38.54200 N, 86.56122 W, (TPS, JLB), 28 June 2004 (1 MI, 9 MII, 37 F, 34 juv), INBS 848. Upper Sulphur Creek, Abydel Road bridge, 2.3 km E West Baden Springs, French Lick Twp, 38.57078 N, 86.58461 W, (TPS), 29 June 2004, (2 MI, 1 MII, 2 F), INBS 849. French Lick Creek, CR 410 S bridge, 6.3 km SSE French Lick, Jackson Twp, 38.49564 N, 86.60119 W, (TPS, ERL, SLW, JLB), 28 June 2004, (5 MII, 4 F, 4 juv), INBS 850. Unnamed tributary French Lick Creek, CR 625 W bridge, 5.5 km SE French Lick, French Lick Twp, 38.51430 N, 86.57527 W, (TPS), 28 June 2004 (4 MI, 13 MII, 24 F, 3 juv), INBS 851. French Lick Creek, SR 145 bridge, 6.1 km SSE French Lick, Jackson Twp, 38.49571 N, 86.60317 W, (TPS, SLW), 2 September 2004, (5 MI, 10 MII, 25 F), INBS 852. French Lick Creek, CR 300 S bridge, 4.3 km S French Lick, French Lick Twp, 38.51249 N, 86.61496 W, (TPS, ERL, JLB, SLW), 28 June 2004, (*1 MI, 9 MII, 13 F, 5 juv), INBS 853. French Lick Creek, Old SR 145, 2.7 km S French Lick, French Lick Twp, 38.53062 N, 86.61094 W, (TPS, SLW), 2 September 2004, (4 MI, 1 MII, 11 F), INBS 854. Unnamed tributary French Lick Creek, CR 75 S bridge, 1.3 km SE French Lick, French Lick Twp, 38.54354 N, 86.60658 W, (TPS), 29 June 2004, (3 F), INBS 855. French Lick Creek, Sinclair Street bridge, 0.8 km W West Baden Springs, French Lick Twp, 38.56346 N, 86.60555 W, (TPS), 19 July 2004, (6 MII, 12 F), INBS 856. French Lick Creek, West Baden Springs Hotel driveway bridge, West Baden Springs, French Lick Twp, 38.56702 N, 86.61398 W, (TPS), 19 July 2004, (5 MII, 3 F), INBS 857. Sulphur Creek, CR 500 N bridge, 2.6 km SSW Bonds, Northwest Twp, 38.62035 N, 86.63228 W, (TPS, AT, JLB, ERL, SLW), 30 June 2004, (4 MI, *21 MII, *10 F, 8 juv), INBS 858. Unnamed tributary Lost River, CR 1125 W bridge, 4.3 km W French Lick, French Lick Twp, 38.54475 N, 86.67119 W, (TPS), 12 July 2004, (4 MI, 5 MII, 10 F, 2 juv), INBS 860. Unnamed tributary Lost River, CR 425 N bridge, 2.6 km WSW Orangeville, Orangeville Twp, 38.62129 N, 86.58393 W, (TPS, JLB, ERL, SLW), 29 June 2004, (1 MI, 13 juv), INBS 869. *Washington County:* Lost River, Vernon School Road bridge, 2 mi SE Claysville, Vernon Twp, 38.59304 N, 86.27104 W, (TPS, BEF, KGS), 18 March 1999, (2 MI, 1 MII, 3 F), INBS 831. Lost River (including unnamed tributary mouth), Satillo-Livonia Road bridge, 2.5 mi NW Livonia, Vernon Twp, 38.59349 N, 86.29107 W, (TPS, BEF, KGS), 18 March 1999, (4 F), INBS 832.

## ACKNOWLEDGMENTS

The authors appreciate field assistance from S.L. Worden, J.L. Burskey, E.R. Lawrence, K. Gremillion-Smith, and B.E. Fisher. We thank C.A. Taylor, INHS, and R.F. Thoma (OSU) for assistance and professional courtesies. R.F. Thoma provided an initial review of this manuscript and two anonymous reviewers improved the submitted manuscript. We appreciate the assistance of K. Reed and G. Keel for providing records from the USNM and collection number assignments for type specimens, R.F. Thoma (OSUMC), and C.A. Taylor (INHS) provided collection number assignments for paratypes from their respective institutions. We are grateful to S.L. Worden (INBS) for preparing the specimen examined list. Line drawn illustrations in Figs. 3–12 were prepared by B. Simon, the color photograph in Fig. 2 was taken by TPS, and CCM prepared the map in Fig. 13. No opinions, expressed or implied, should be considered an endorsement by the U.S. Forest Service. This study was funded by U.S. Forest Service grant NF1M012559-0912 to TPS.

## LITERATURE CITED

Bouchard, R.W. 1976. Geography and ecology of crayfishes of the Cumberland Plateau and Cumberland Mountains, Kentucky, Virginia, Tennessee, Georgia, and Alabama. Part I: The genera *Procambarus* and *Orconectes*. Pp. 563–584. *In*

(J.W. Avault, Jr., ed.). Freshwater Crayfish. Louisiana State University Division of Continuing Education, Baton Rouge, Louisiana.

Bundy, W.F. 1877. On the Cambari of northern Indiana. Proceedings of the Academy of Natural Sciences of Philadelphia 29:171–174.

Creaser, E.P. 1933. Descriptions of some new and poorly known species of North American crayfishes. Occasional Papers of the Museum of Zoology, University of Michigan 275. 21 pp., 2 pl.

Dubois, J. & M.L. Sharma. 1977. An investigation of the enzymes during degradation in the freshwater crayfish *Orconectes rusticus*, on acclimation to 50% seawater. Science Studies, St. Bonaventure University 32:27–34.

Eberly, W.R. 1955. Summary of the distribution of Indiana crayfishes, including new state and county records. Proceedings of the Indiana Academy of Science 64:281–283.

Faxon, W. 1884. Descriptions of new species of *Cambarus*, to which is added a synonymical list of the known species of *Cambarus* and *Astacus*. Proceedings of the American Academy of Sciences 20:107–158.

Faxon, W. 1885. A revision of the Astacidae, Part I: The genera *Cambarus* and *Astacus*. Memoirs of the Museum of Comparative Zoology at Harvard College 10:*i–vi*, 1–186.

Faxon, W. 1914. Notes on the crayfishes in the United States National Museum and the Museum of Comparative Zoology with descriptions of new species and subspecies to which is appended a catalogue of the known species and subspecies. Memoirs of the Museum of Comparative Zoology at Harvard College 40(8):351–427, 13 pl.

Fitzpatrick, Jr., J.F. 1987. The subgenera of the crawfish genus *Orconectes* (Decapoda: Cambaridae). Proceedings of the Biological Society of Washington 100:44–74.

Girard, C. 1852. A revision of the North American Astaci, with observations on their habits and geographical distributions. Proceedings of the Academy of Natural Sciences of Philadelphia 6: 87–91.

Hagen, H.A. 1870. Monograph of the North American Astacidae. In Illustrated Catalogue of the Museum of Comparative Zoology at Harvard College 3:viii + 109 pp., 11 pl.

Hay, W.P. 1891. The crustacean fauna of Indiana. Proceedings of the Indiana Academy of Science 1891:147–150.

Hay, W.P. 1902. Observations on the crustacean fauna of Nickajack Cave, Tennessee, and vicinity. Proceedings of the United States National Museum 25:417–439.

Hobbs, H.H., Jr. 1972. Crayfishes (Astacidae) of North and Middle America. Biota of Freshwater Ecosystems, Identification Manual 9. United States Environmental Protection Agency. Pp. i–x, 1–173.

Hobbs, H.H., Jr. 1974. A checklist of the North and Middle American crayfishes (Decapoda: Astacidae and Cambaridae). Smithsonian Contributions to Zoology 166:1–166.

Hobbs, H.H., Jr. 1989. An illustrated checklist of the American crayfishes (Decapoda: Astacidae, Cambaridae, and Parastacidae). Smithsonian Contributions to Zoology 480:1–236.

Huner, J.B. 1978. Exploitation of freshwater crayfishes in North America. Fisheries 3(6):2–5.

Ortmann, A.E. 1905. The mutual affinities of the species of the genus *Cambarus*, and their dispersal over the United States. Proceedings of the American Philosophical Society 44:91–136.

Ortmann, A.E. 1931. Crawfishes of the southern Appalachians and the Cumberland Plateau. Annals of the Carnegie Museum 20:61–160.

Page, L.M. & G.B. Mottesi. 1995. The distribution and status of the Indiana crayfish, *Orconectes indianensis*, with comments on the crayfishes of Indiana. Proceedings of the Indiana Academy of Science 104:103–111.

Simon, T.P. 2001. Checklist of the crayfish and freshwater shrimp (Decapoda) of Indiana. Proceedings of the Indiana Academy of Science 110:104–110.

Taylor, C.A. 2000. Systematic studies of the *Orconectes juvenilis* complex (Decapoda: Cambaridae), with descriptions of two new species. Journal of Crustacean Biology 20(1):132–152.

*Manuscript received 20 May 2005, revised 10 June 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):55–61

# NOTES ON INDIANA CRAYFISH (DECAPODA: CAMBARIDAE) WITH COMMENTS ON DISTRIBUTION, TAXONOMY, LIFE HISTORY, AND HABITAT

**Thomas P. Simon, Matthew Weisheit, Elizabeth Seabrook, Lori Freeman, Scott Johnson, Lynn Englum, Katherine W. Jorck, Matthew Abernathy** and **Thomas P. Simon IV**: Aquatic Research Center, Indiana Biological Survey, 6440 Fairfax Road, Bloomington, Indiana 47401 USA

**ABSTRACT.** Large collections of crayfish made throughout Indiana during the past several years have increased our knowledge of various aspects of the biology of Indiana's crayfish fauna, including *Orconectes (F.) indianensis*, a species that had conservation status. New information on distribution, taxonomy, life history, or habitat is provided for *Orconectes (Faxonius) indianensis*, *Orconectes (Trisellescens) immunis*, *Orconectes (Crockerinus) propinquus*, *Orconectes (Procericambarus) rusticus*, *Cambarus (Tubericambarus)* sp. "A," *Cambarus (Erebicambarus) tenebrosus*, *Cambarus (Erebicambarus) laevis*, *Procambarus (Ortmannicus) acutus* and *P. (Scapulicambarus) clarkii*. Reproductive biology, fecundity, egg diameter size, and instar lengths are provided for *Orconectes (F.) indianensis*, *Orconectes (T.) immunis*, *Orconectes (C.) propinquus*, *Cambarus (T.)* sp. "A," and *Procambarus (S.) clarkii*, including chronology of appearance on the female abdomen. The largest ova diameters belong to *Cambarus (T.)* sp. "A" and *Procambarus (S.) clarkii* with diameters between 2.1–2.5 mm, while *Orconectes (T.) immunis* had the smallest ova ranging between 1.4–2.0 mm.

**Keywords:** Distribution, taxonomy, life history, habitat

Hobbs (1989), less than 20 years ago, indicated that 17 species of crayfish were known to occur in Indiana. Our knowledge of the biology and zoogeography of Indiana species is limited to mostly those species occurring in the northern portions of the state; however, the species composition of the southern portions of the state has been clouded by taxonomic and ecological uncertainties. Since the publication of the Hobbs list, Page & Mottesi (1995) and Simon (2001) have presented checklists of the crayfish fauna of Indiana, adding several species previously unknown to occur in the state, and have reported on the recommended conservation status. Simon & Thoma (unpubl. data) and Simon (2002) expanded the range of another introduced crayfish, while Taylor (2000) described a new species that ranges into the state. Further investigation and field surveys have discovered additional new species (Simon unpubl. data).

Several hundred collections made during the past several years have added significantly to our understanding of the biology of many Indiana crayfish, including several species that have limited ranges or the greatest parts of their ranges within the State. This paper provides new distribution, taxonomic, and habitat data for nine species that occur in Indiana, and reproductive information on five of these species.

## METHODS

Crayfish carapace length (CL) was measured from the anterior tip of the rostrum to the posterior margin of the areola using digital calipers that measured to the nearest 0.1 mm. Ova diameters and instar lengths were measured using an optical micrometer inserted in a Bausch and Lomb Stereozoom 7 microscope. All ova and instars were measured to the nearest 0.01 mm. All crayfish were collected legally, with permission from the appropriate state government agencies. Life history and distribution information is based on new observations from referenced Indiana collections. We do not repeat previously published distribution information published in Simon & Thoma (2003) and Thoma et al. (in press); however, information presented on significant reproductive biology information is based on material from the Patoka River collections which is included for the reader's benefit.

The following abbreviations are used in the text: INBS = Indiana Biological Survey, Crustacean Collection, Bloomington; US = United States highway; SR = Indiana state highway; CR = Indiana secondary (county) road; d/s = downstream; lat = latitude; lon = longitude. Names of collectors are provided in first usage, initials thereafter. Specimen abbreviations include PCL = postorbital carapace length, TCL = total carapace length, MI = first form male, MII = second form male, F = female, FE = female with eggs, FOVIG = ovigerous female, juv = juvenile, and P = partial specimen (usually a chelae). Catalogue numbers are those of voucher specimens in the INBS Crustacean Collection unless otherwise noted.

## RESULTS AND DISCUSSION

### *Orconectes (Faxonius) indianensis* (Hay) Indiana Crayfish

The Indiana crayfish *Orconectes (F.) indianensis* is a state Species of Special Concern and was considered a federal candidate species until the release of a conservation status report published by Page (1994). Simon (2001) recommended that the state list the Species as Special Concern because of its apparent rarity until further studies could be completed.

**Distribution.**—Page & Mottesi (1995) determined that *O. (F.) indianensis* did not warrant conservation status because the species had been found at 10 locations in Indiana. The majority of these sites were in the Patoka River drainage, an area that is threatened from oil and gas exploration and coal extraction (Simon et al. 1995; Simon et al. 2005). The species presence was investigated in the Patoka River drainage to determine whether additional occupied locations existed (Simon & Thoma 2003). Simon & Thoma (unpubl. data) evaluated the conservation status of the species in the Patoka River drainage and found that it was much more common than previously known.

The species was collected from the following additional locations: **PATOKA RIVER DRAINAGE:** *Dubois County:* Little Flat Creek, CR 300 W bridge, 2 mi SE Otwell, Madison Twp., lat 38.4225 N, lon 87.0687 W, 11 April 2001,, 4 FE, 4 FOVIG, 10 MI, 10 MII, (Thomas P. Simon). Mill Creek, CR 600 N bridge, 1.5 mi SW Haysville, Boone Twp., lat 38.4672 N, lon 86.7563 W, 11 April 2001, 4 FE, 1 MI, 1 MII, 2 juv, (TPS). Davis Creek, Cuzco Road bridge, Crystal, Columbia Twp., lat 38.4878 N, lon 86.7563 W, 19 May 2001, 2 FOVIG, 25 MI, 18 MII, (TPS, Roger F. Thoma & Foster Purrington). *Orange County:* Cane Creek, CR 500 S bridge, 4.5 mi S French Lick, Jackson Twp., lat 38.4790 N, lon 86.6588 W, 19 May 2001, 47 FE, 2 FOVIG, 59 MII, (TPS, RFT & FP). Unnamed tributary Patoka River, CR 825 S bridge, Valeen, Southeast Twp., lat 38.4342 lon 86.3975 W, 21 May 2001, 1 FE, 1 FOVIG, (TPS, RFT & FP).

**Life history.**—Limited information is available on the reproductive biology of *O. (F.) indianensis*. The species is lithophilic, requiring minimal amounts of rock, and usually associated with the areas beneath bridges (Simon & Thoma unpubl. data). The earliest date in 2001 that a female was found carrying ova was mid-April, while the latest that instars were observed was late May (Table 1). Page (1985) reported females carrying ova during March and April and young only during May. Ova ranged from 1.2–1.8 mm diameter (Table 1). First form males were collected in Indiana during April, July, and October, while Page (1985) indicated that first form males were present in Illinois during March, August, September, and October.

### *Orconectes (Trisellescens) immunis* (Hagen) Calico Crayfish

**Distribution.**—*Orconectes (G.) immunis* has one of the widest geographical ranges, occurring from Maine and Connecticut to eastern Colorado and Wyoming, and from Alabama to southern Manitoba, Ontario, and Quebec (Hobbs 1989). The distribution of the species in Indiana has not been completely surveyed; however, it occurs statewide with perhaps the greatest abundance in southwestern Indiana.

**Life history.**—Despite the thousands of specimens residing in research collections, limited life history information is available for the species in Indiana. Life history information has been reported for northern populations from Ontario (Crocker & Barr 1968), Wisconsin (Hobbs & Jass 1988), and Illinois

Table 1.—Reproduction biology of select crayfish species including information on chronology of appearance, ova size, and instar development. Columns include Indiana Biological Survey (INBS) Crustacean Collection number, postorbital carapace length (PCL), date of collection, number, and condition (ova and instar size and number).

| Collection number | PCL (mm) | Date | Condition |
|---|---|---|---|
| *Orconectes* (*F.*) *indianensis* | | | |
| 93 | 22 | 11 April 2001 | 155 1st instar young, ca. 3–4 mm PCL (rostrum undeveloped); |
| | 25 | | 205 1st instar young, ca. 3–4 mm PCL (rostrum undeveloped) |
| | 21 | | 101 ova with eyespots on verge of eclosion, ca. 1.5-mm diameter |
| | 22 | | 159 ova, 1.2–1.8 mm diameter |
| 79 | 23 | 11 April 2001 | 209 ova, 1.5–1.7 mm diameter |
| 83 | 19 | 19 May 2001 | 16 1st instars, ca. 3–4 mm PCL (rostrum undeveloped) |
| 51 | 14 | | 23 1st instars, ca. 3–4 mm PCL (rostrum undeveloped) |
| 200 | 21 | 19 May 2001 | 20 1st instars, ca. 3–4 mm PCL (rostrum undeveloped) |
| | 17 | | 17 1st instars, ca. 3–4 mm PCL (rostrum undeveloped) |
| 193 | 20 | 21 May 2001 | 108 1st instars, ca. 4 mm PCL |
| *Orconectes* (*T.*) *immunis* | | | |
| 67 | 30 | 4 April 2001 | 367 ova, 1.7–2.0 mm diameter |
| 128 | 21 | 5 April 2001 | 194 ova, 1.0–1.5 mm diameter |
| 141 | 22 | 5 April 2001 | 194 ova, 1.5–2.0 mm diameter |
| | 27 | | 237 ova, 1.4–2.1 mm diameter |
| 70 | 23 | 5 April 2001 | 204 ova, 1.2–1.8 mm diameter |
| | 25 | | 229 ova, 1.6–1.8 mm diameter |
| 73 | 32 | 5 April 2001 | 191 ova, 1.9–2.1 mm diameter |
| 160 | 18 | 10 April 2001 | 104 ova, 1.4–2.0 mm diameter |
| 178 | 13 | 11 April 2001 | 33 ova, 1.2–1.5 mm diameter |
| 87 | 21 | 11 April 2001 | 185 ova, 1.5–1.7 mm diameter |
| 87 | 26 | | 372 ova, 1.5–1.8 mm diameter |
| 87 | 26 | | 68 ova, 1.1–2.0 mm diameter |
| 126 | 25 | 11 April 2001 | 333 1st instar young, ca. 3 mm PCL (rostrum undeveloped): 1 ova with eyespots on verge of eclosion, ca. 1.8 mm diameter |
| 136 | 22 | 11 April 2001 | 90 ova, 1.5–1.8 mm diameter |
| 136 | 23 | | 184 ova, 1.7–2.0 mm diameter |
| 162 | 24 | 11 April 2001 | 33 1st instars, ca. 3–4 mm PCL |
| 136 | 27 | | 58 1st instars, ca 3–4 mm PCL |
| 56 | 23 | 11 April 2001 | 209 ova, 1.6–2.0 mm diameter |
| *Orconectes* (*C.*) *propinquus* | | | |
| 215 | 25 | 16 June 2001 | 232 ova, 2.0–2.1 mm diameter |
| 219 | 25 | 2 August 2001 | 34 1st instars, ca. 4 mm PCL |
| 222 | 20 | 21 August 2001 | 5 ova with eyespots on verge of eclosion, ca. 2.0–2.2 mm diameter |
| *Cambarus* (*T.*) sp. "A" | | | |
| 67 | 29 | 4 April 2001 | 75 1st instar young, ca. 4 mm PCL (rostrum undeveloped): 1 ova with eyespots on verge of eclosion, ca. 2.4 mm diameter |
| 67 | 34 | | 118 1st instar young, ca. 4–5 mm PCL |
| 163 | 47 | 23 March 2001 | 234 ova, 2.1–2.5 mm diameter |
| 64 | 35 | 21 May 2001 | 36 instars, ca. 4–5 mm PCL; 5 ova, 2.1–2.4 mm diameter |
| 224 | 42 | 16 June 2001 | 72 1st instars, ca. 4–5 mm PCL; 36 ova, 2.1–2.5 mm diameter |
| *Procambarus* (*S.*) *clarkii* | | | |
| 226 | 34 | 8 July 2000 | 198 ova, 2.0–2.5 diameter |
| 227 | 37 | 21 September 2002 | 132 1st instar young, ca. 3–4 mm PCL (rostrum undeveloped): 4 ova with eyespots on verge of eclosion, ca. 2.0–2.4 mm diameter |

(Page 1985). Detailed life histories for this species have been done by Tack (1941) and Caldwell & Bovbjerg (1964).

First form males were collected from southern Indiana during April, May, July, and August. The earliest ovigerous female found was during early April in the South Fork Patoka River, CR 300 E bridge, 1.5 mi SE Coe, Monroe Twp., lat 38.2872 N, lon 87.2193 W, 4 April 2001, (TPS) (Table 1). Ova ranged in diameter from 1.0–2.0 mm. Juvenile crayfish were collected in mid-May and July.

### *Orconectes (Crockerinus) propinquus* (Girard)
### Northern Clearwater Crayfish

**Distribution.**—Our data are based on these specimens: **EAST FORK WHITE RIVER DRAINAGE:** *Monroe County:* Jordan River, 1.5 mi E Bloomington, Bloomington Twp., lat. 39.16648 lon 86.52454, (TPS). Jackson Creek, d/s Rogers Road, 2.75 mi SE Bloomington, Perry Twp., 16–18 June 2002, lat 39.13656 N, lon 86.50660 W, (TPS & Cameron C. Simon). Bean Blossom Creek, Currie Pike Rd, 7 mi N Bloomington, Bloomington Twp., 26 June 2001, lat 39.2377 N, lon 86.5275 W, (TPS).

**Life history.**—Most life history information for *Orconectes (C.) propinquus* is based on data from Ontario, Wisconsin, and limited data from Illinois (Crocker & Barr 1968; Hobbs & Jass 1988; Page 1985). Life history data from the southern portions of the range in Indiana are lacking. First form males from the above sites in southern Indiana were collected during April, July, August, and October. Females carried ova from mid-June until late August (Table 1). Ova ranged from 2.0–2.2 mm diameter.

### *Orconectes (Procericambarus) rusticus* (Girard)
### Rusty Crayfish

**Distribution.**—The native range of *Orconectes (P.) rusticus* in Indiana includes the Whitewater, Greater Miami, and Maumee river drainages (Hay 1896). The transport and spread of this species through bait-bucket transfer of adults has had devasting effects on the aquatic assemblages of northern Wisconsin lakes (Lodge et al. 1986; Lodge et al. 1994). Taylor & Redmer (1996) reported on the spread of *Orconectes rusticus* in Illinois, but no information exists for the status of the species in Indiana. Specimens obtained from the Bureau of Water Quality, City of Muncie, from surveys during the early 1970s document the species as common in the upper West Fork White River from multiple locations near Muncie (Simon unpubl. data). Surveys in the West Fork of the White River found the species to be dominant in tributaries extending from the Ohio state line west to Indianapolis and in the upper East Fork and major tributaries (Simon unpubl. data). Taylor & Redmer (1996) documented the spread of *O. rusticus* in Illinois. A similar study has not been completed in Indiana so exact distribution of the species is unknown. A life history study is also being conducted in the Little Mississinewa River, Randolph County.

### *Cambarus (Tubericambarus)* sp. "A"
### Painted-hand Mudbug

**Taxonomy.**—Jezerinac (1993) created the subgenus *Tubericambarus* and indicated that there were multiple undescribed species within the *Cambarus diogenes* complex. The species assigned as *Cambarus (T.)* sp. "A" by Jezerinac (1993) is currently being described (Thoma et al. in press). This species is distributed from southeastern Michigan south to Tennessee, and from western Pennsylvania to eastern Missouri.

**Distribution.**—The type locality is **PATOKA RIVER DRAINAGE:** *Pike County:* Flat Creek, CR 124 S bridge, Washington Twp., lat 38.4019 N, lon 87.3066 W, 24 March 2001, 4 MI, 3 MII, 8 F (TPS, RFT & FP). Thoma et al. (in press) provides thorough distribution information for this species. Further research on the *Cambarus diogenes* complex will result in the recognition of other species from Indiana, and possibly another six species throughout that species' former range.

**Life history.**—First form males were collected from southern Indiana in 2001 during March, April, and May. Females were first found carrying ova in early April, and instars were last collected in mid-June (Table 1). Juveniles were collected in mid-May.

### *Cambarus (Erebicambarus) laevis* Faxon
### Karst Crayfish

**Taxonomy.**—Taylor (1997) synonomized *Cambarus (E.) laevis* with *Cambarus (E.) tenebrosus* based on morphological characters and found fewer differences among sites than within sites. However, based on our observations, several key morphological differences were observed among Indiana populations of these two forms. We observed preliminary differences in first form male gonopod structure, branchiostegal tubercle presence, chelae shape, size of first form males, and pigmentation (Simon unpubl. data).

**Distribution.**—*Cambarus (E.) laevis* is a wide-ranging species found throughout central and southern Indiana, but few published records exist for the species outside of Monroe County. The following collections, all represented by voucher specimens, establish the presence of *Cambarus (E.) tenebrosus* into southern Indiana: **EAST FORK WHITE RIVER:** *Monroe County:* Unnamed tributary, Birdie Galien Road, 8.5 mi E Bloomington, Salt Creek Twp., lat 39.15301 N, lon 86.38444 W, 18 December 1998, 1 F, (TPS, TPS IV, CCS). **PATOKA RIVER DRAINAGE:** *Pike County:* Unnamed tributary Patoka River, SR 364 bridge, 1.5 mi SE Winslow, Marion Twp., lat. 38.3558 N, lon 87.16683 W, 18 May 2001, 1 F, 2 P (TPS). *Dubois County:* Mill Creek, CR 600 N bridge, 1.5 mi SW Haysville, Boone Twp., lat 38.46717 N, lon 86.94717 W, 27 March 2001, 1 F (TPS). *Orange County:* Cane Creek, CR 500 S bridge, 4.5 mi S French Lick, Jackson Twp., lat 38.4790 N, lon 86.65883 W, 11 May 2001, 1 F, 3 MII, 2 juv, (TPS, RFT & FP). Cane Creek, Cuzco Road, S Cuzco, Columbia Twp., lat. 38.4705 N, lon 86.7220, 1 F (TPS, RFT & FP). Young's Creek, CR 600 S bridge, Hoosier National Forest, Greenfield Twp., lat. 38.51583 N, lon. 86.51567 W, 11 April 2001, 1 F, 1 MI, 1 MII, 2 juv, (TPS, RFT & FP). Unnamed tributary Patoka River, CR 825 S bridge, Valeen, Southeast Twp., lat 38.434167 N, lon 86.3975 W, 21 May 2001, 1 F, (TPS, RFT & FP). Patoka River, CR 500 E bridge, 2 mi SSE Chambersburg, Stampers Creek Twp., lat 38.48433 N, lon 86.37367 W, 7 June 2001, 1 F, (TPS).

**Life history.**—The karst crayfish *Cambarus (E.) laevis* is generally found in small brooks, creeks, and streams beneath large flat stones. These stones can be distributed throughout the width of the stream, but generally are found along the edges of the stream in the greatest current. First form males from the Patoka River drainage were collected in May.

### *Cambarus (Erebicambarus) tenebrosus* Hay
### Cavespring Crayfish

**Taxonomy.**—We recognize Taylor's (1997) recommendation to synonomize *Cambarus (E.) laevis* with *Cambarus (E.) tenebrosus*, but we have chosen to keep these two forms separate until further cladistic and genetic analysis can be accomplished since we observed several differences, which might prove that the species are distinct.

**Distribution.**—*Cambarus (E.) tenebrosus* occurs in southern Indiana along the edge of the Wisconsian glacial advance south into karst areas. Distribution of the species occurring primarily throughout Monroe County and further south has not been well-documented. Our new records include: **PATOKA RIVER DRAINAGE:** *Orange County:* Unnamed tributary Patoka River, Spring Spring's cave outlet, CR 475, Stumpers Creek Twp., lat 38.48966 N, lon 86.36317 W, 21 May 2001, 1 FE, 1 MI, 1 MII, (TPS, RFT & FP).

**Life history.**—The cavespring crayfish is generally found within caves near the outlet of small to moderate-sized streams beneath large flat stones with non-imbedded cobble substrates. Large adults are generally found beneath the largest slab stones along either the edge or in the center of the stream. First form males were collected during December.

### *Procambarus (Ortmannicus) acutus* (Girard)
### White River Crayfish

**Distribution.**—*Procambarus (O.) acutus* is widespread and abundant in the Coastal Plain and the Piedmont Plateau of North Carolina (Cooper 2002), but is limited to lowland streams in Indiana. The following are new vouchered records for the species: **PATOKA RIVER DRAINAGE:** *Pike County:* Unnamed tributary Cup Creek, unnamed CR, 0.75 mi NW Pikeville, Lockhart Twp., lat 38.32733 N, lon 87.12893 W, 26 March 2001, 1 F, (TPS, RFT & FP). *Dubois County:* Indian Creek, SR 64 bridge, lat 38.299333 N, lon 86.91533 W, 18 May 2001, 1 F,(TPS, RFT & FP). Short Creek, Sunset Road, 1.5 mi SE Huntingburg, Ferdinand Twp., lat. 38.2743 N, lon. 86.9322 W, 18 May 2001, 1 F, (TPS, RFT & FP).

**Life history.**—We have collected this species from the West Fork White River drainage in intermittent and perennial headwater streams. The species is more common in southwestern Indiana, occurring in wetlands, small vernal ponds, and stream habitats (Simon unpubl. data).

### *Procambarus (Scapulicambarus) clarkii* (Girard)
### Louisiana Red Swamp Crayfish

**Distribution.**—Page (1985) indicated that *Procambarus (S.) clarkii* was limited to the Coastal Plain lowlands of Illinois and that the species was rare in Indiana. Simon & Thoma (unpubl. data) found the species along the southern shore of Lake Michigan in drowned river mouth coastal wetlands. The species has since been found in additional locations including: **LAKE MICHIGAN DRAINAGE:** *Lake County:* East Branch Grand Calumet River, d/s Kennedy Avenue, East Chicago, Lake Twp., 18 November 1999, 1 FOVIG, (TPS & James R. Smith). West Branch of the Grand Calumet River, d/s Indianapolis Boulevard, East Chicago, Lake Twp., 2 December 1999, lat 41.61430 N, 8747975 W, 3 FOVIG, 1 MI, (TPS & Alex Peine).

**Life history.**—Ovigerous females collected from the West Branch of the Grand Calumet River and from Illinois, Lake County, Dead River mouth in Illinois Beach State Park included females with 1st instar and ova with eyespots on the verge of eclosion (Table 1). First form males were collected in July, September, November, and December from Indiana and Illinois populations. Ovigerous females had ova that ranged from 2.0–2.5 mm diameter (Table 1).

## ACKNOWLEDGMENTS

We appreciate the specimens provided by many colleagues. Without their diligent efforts and well-documented voucher specimens we would not be as knowledgeable about the distribution and biology of these species. Special thanks to Anthony Brannam, Natural Resource Conservation Service; Brant E. Fisher, Indiana Department of Natural Resources; Stacy Sobat, Indiana Department of Environmental Management; and Dale Sparks, Indiana State University, all of whom provided crustaceans during the course of their own various field surveys.

## LITERATURE CITED

Caldwell, M.J. & R.V. Bovbjerg. 1964. Natural history of the two crayfish of northwestern Iowa, *Orconectes virilis* and *Orconectes immunis*. Iowa Academy of Science Proceedings 76:463–472.

Cooper, J.E. 2002. North Carolina crayfishes (Decapoda: Cambaridae): Notes on distribution, taxonomy, life history, and habitat. Journal of the North Carolina Academy of Science 118:167–180.

Crocker, D.W. & D.W. Barr. 1968. Handbook of the Crayfishes of Ontario. Royal Ontario Museum, University of Toronto Press, Toronto.

Hay, W.P. 1896. The crawfishes of the state of Indiana. Pp. 475–507, *In* 20th Annual Report of the Department of Geology and Natural Resources of Indiana.

Hobbs, H.H., Jr. 1989. An illustrated checklist of the American crayfishes (Decapoda: Astacidae, Cambaridae, and Parastacidae). Smithsonian Contributions in Zoology 480:1–236.

Hobbs, H.H., III & J.P. Jass. 1988. The Wisconsin Decapod Crustaceans (Cambaridae, Palaemonidae). Contributions of the Milwaukee Public Museum, viii + 177 pp.

Jezerinac, R.F. 1993. A new subgenus and species of crayfish (Decapoda: Cambaridae) of the genus *Cambarus*, with an amended description of the subgenus *Lacunicambarus*. Proceedings of the Biological Society of Washington 106:532–544.

Lodge, D.M., T.K. Kratz & G.M. Capelli. 1986. Long-term dynamics of three crayfish species in Trout Lake, Wisconsin. Canadian Journal of Fisheries and Aquatic Sciences 43:993–998.

Lodge, D.M., M.W. Kershner, J.E. Aloi & A.P. Covich. 1994. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. Ecology 75:1265–1281.

Page, L.M. 1985. The crayfishes and shrimps (Decapoda) of Illinois. Illinois Natural History Survey Bulletin 4:335–448.

Page, L.M. 1994. The distribution and status of the Indiana crayfish, *Orconectes indianensis*. Illinois Natural History Survey, Champaign. Center for Biodiversity, Technical Report 1994(2).

Page, L.M. & G.B. Mottesi. 1995. The distribution and status of the Indiana crayfish, *Orconectes indianensis*, with comments on the crayfishes of Indiana. Proceedings of the Indiana Academy of Science 104:103–111.

Simon, T.P. 2001. Checklist of the crayfish and freshwater shrimp (Decapoda) of Indiana. Proceedings of the Indiana Academy of Science 110:104–110.

Simon, T.P. 2002. North American crayfish: Introductions from bait bucket and the aquarium trade. Lakeline 22:52–54.

Simon, T.P., R.L. Dufour & B.E. Fisher. 2005. Changes in the biological integrity of fish communities in the Patoka River as a result of anthropogenic disturbance from 1888 to 2001. Pp. 245–261, *In* Historical Changes in Large River Fish Assemblages of the Americas. (J.N. Rinne, R.M. Hughes & B. Calamusso, eds.). American Fisheries Society, Bethesda, Maryland.

Simon, T.P., S.A. Sobiech, T.H. Cervone & N.E. Morales. 1995. Historical and present distribution of fishes in the Patoka River basin: Pike, Gibson, and Dubois counties, Indiana. Proceedings of the Indiana Academy of Science 104: 193–206.

Simon, T.P. & R.F. Thoma. 2003. Distribution patterns of freshwater shrimp and crayfish (Decapoda: Cambaridae) in the Patoka River basin of Indiana. Proceedings of the Indiana Academy of Science 112:175–185.

Tack, P.I. 1941. The life history and ecology of the crayfish, *Cambarus immunis* Hagen. American Midland Naturalist 25:420–446.

Taylor, C.A. 1997. Taxonomic status of members of the subgenus *Erebicambarus*, genus *Cambarus* (Decapoda: Cambaridae), east of the Mississippi River. Journal of Crustacean Biology 17: 352–360.

Taylor, C.A. 2000. Systematic studies of the *Orconectes juvenalis* complex (Decapoda: Cambaridae), with descriptions of two new species. Journal of Crustacean Biology 20:132–152.

Taylor, C.A. & M. Redmer. 1996. Dispersal of the crayfish *Orconectes rusticus* in Illinois, with notes on species displacement and habitat preference. Journal of Crustacean Biology 16:547–551.

Thoma, R.F., R.F. Jezernac & T.P. Simon. in press. *Cambarus (Tubericambarus) polychromatus* (Decapoda: Cambaridae), a new species of crayfish from the midwestern United States. Proceedings of the Biological Society of Washington.

*Manuscript received 16 March 2005, revised 19 May 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):62–64

# DISCOVERY OF AN EXOTIC ASIAN MOSQUITO, *OCHLEROTATUS JAPONICUS*, (DIPTERA: CULICIDAE) IN SOUTHERN INDIANA

**Steven P. Moberly**, **Craig Lalor** and **Mollie McDonough**: School of Natural Sciences, Indiana University Southeast, New Albany, Indiana 47150 USA

**Brad Foster** and **Adam Estes**: Indiana State Department of Health, 635 North Barnhill Drive, Indianapolis, Indiana 46202 USA

**Douglas J. Bentfield**: Clark County Health Department, 1320 Duncan Ave., Jeffersonville, Indiana 47130 USA

**ABSTRACT.** *Ochlerotatus (Oc.) japonicus*, an exotic Asian mosquito, appeared in New York, New Jersey and Connecticut in 1998. The species now inhabits 20 eastern states, Washington state and Quebec, Canada. *Oc. japonicus* was found at three sites near an existing railway system in Clark County, southern Indiana, in July 2004. During the 2004 sampling season, the species was found in small numbers at 20 of 100 sampling locations in Clark, Floyd and Harrison counties. Most early samples were taken near existing railway and interstate transportation systems. Later, in September and October, the mosquito expanded its range into other habitats. This invading non-indigenous species should be monitored closely since it is a known vector for several viral pathogens including those responsible for West Nile fever, Saint Louis encephalitis, Japanese encephalitis and eastern equine encephalitis.

**Keywords:** *Ochlerotatus japonicus*, Indiana, Diptera, Culicidae

*Ochlerotatus (Oc.) japonicus*, the Asian rock pool mosquito, is an exotic species that was introduced into the United States in 1998, possibly in shipments of used tires entering New York, New Jersey and Connecticut (Peyton et al. 1999). Since the initial discoveries, the mosquito has been quickly expanding its range (Fonseca et al. 2001). By the end of 2003, it was found in Quebec, Canada and 19 states: Connecticut, Delaware, Georgia, Maine, Massachusetts, Maryland, North Carolina, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, Vermont, Washington and West Virginia (Scott 2004). It is almost certain that the Ohio specimens found in 1999 came from New York or New Jersey since they were trapped near a tire retreading business that regularly receives shipments from the east coast (Berry 1999).

Since *Ochlerotatus japonicus* has a short flight range of less than 1.6 km, its rapid movement into several states presumably was facilitated by interstate trade and transit (Fonseca et al. 2001). Studies have shown that another Asian mosquito, *Aedes (Ae.) albopictus*, may have arrived in Texas in a shipment of used tires and then spread across southeastern USA along the interstate highway system (Moore & Mitchell 1997). *Aedes albopictus* currently is very common in many southern states. *Ochlerotatus japonicus* could be moving westward in a similar fashion, hitching a ride in tires and other containers found on barges, trains and trucks. Alternatively, the species may have had a more direct transit via airline, train or truck traffic from the west coast.

## RESULTS

We report the first Indiana appearance of *Ochlerototus (Oc.) japonicus* in Clark County, southern Indiana. In July 2004, the first specimens of *Oc. japonicus* appeared in mosquito nets set by Indiana University Southeast researchers. We suspected the mosquito was a new species for Indiana and forwarded the unidentified specimens to the Indiana State Department of Health where Brad Foster and Adam Estes verified the identification. In August 2004, Dina Fonseca of the Smithsonian Institution further substantiated the identification using mitochondrial DNA-sequencing techniques.

The first Indiana specimens were trapped in early July 2004 in both urban and rural areas of Clark County, very near an existing active railway. In the immediate vicinity of the trap locations, we found water-filled artificial containers, small drainage systems with pooled water and older trees with tree holes. These locations correspond well with published habitat data from New Jersey, Connecticut and New York (Andreadis et al. 2001). Nets in which *Oc. japonicus* were found typically contained specimens of *Culex pipiens* and *Aedes albopictus*.

After the initial finding, we established base-line information at our sampling locations so that we can follow the distribution and numbers in subsequent years. Briefly, during sampling from May–October 2004, we found 48 *Oc. japonicus* in about 20,000 mosquito specimens at 20 of 100 sampling locations. We also found the species at one location in Salem, Indiana (Washington County). Of these 21 locations, 15 were less than 0.4 km from the railway system. As the sampling season progressed, specimens were found in more traditional settings near failing septic systems (2 stations), the interstate highway system (2 stations), arboreal settings (1 station) and a tire dump (1 station).

## DISCUSSION

The failure to detect *Ochlerotatus japonicus* in Indiana in previous sampling seasons may be related to the low capture frequency of this species using traditional light and gravid trap methods. Andreadis et al. (2001) found *Oc. japonicus* in 0.5% of 182,590 adult female mosquitoes taken in 1999 and 2000. In these samples, the light and gravid traps produced less than 2.5 mosquitoes per trap.

Our results compare favorably with those published by Andreadis et al. (2001). We found the new mosquito in 0.25% of 20,000 mosquitoes with a capture rate of 1–3 mosquitoes per trap. Once our finding was publicized and other researchers developed search images for this species, other counties began to report its occurrence. Therefore, it is tempting to conclude that the mosquito may have been present for some time and is now being detected because researchers are searching for the organism. In fact, the mosquito could have arrived with *Aedes albopictus* via movement of goods along interstate and water transportation routes. To adequately assess the numbers of *Oc. japonicus* in Indiana, sampling efforts should include collections of larvae from natural habitats where the species is known to lay its eggs (rock pools, tree holes, and spring-fed depressions).

Travel and the rapid transcontinental movement of products are known to be potent forces in the emergence of disease (Wilson 1995). Invading non-indigenous species can cause public health problems, and the number of introductions is expected to rise (Fonseca 2001). In addition to being found in used tires, *Ae. albopictus* and *Oc. japonicus* have also been found in a variety of other materials: Lucky Bamboo (an ornamental lily in the genus *Dracaena*), imported machinery, and in airplanes (Linthicum et al. 2003).

*Ochlerotatus japonicus* is important from a public health perspective because it can spread the pathogens responsible for West Nile virus, St. Louis encephalitis, eastern equine encephalitis, and Japanese encephalitis (Sardelis & Turrell 2001; Sardelis et al. 2002; Sardelis et al. 2003; Takashima & Rosen 1989; Turrell et al. 2001). In Japan, the mosquito sometimes bites humans who venture into forested habitats (Peyton et al. 1999). In Connecticut in wooded habitats, Andreadis et al. (2001) found that human bait enhanced by $CO_2$ attracted *Oc. japonicus*. This suggests that the species will feed on humans.

Unlike many other mosquitoes (e.g., *Ae. albopictus* and *Ae. aegyptii*), *Oc. japonicus* readily inhabits areas such as Hokkaido, Japan where winter temperatures drop below −18 °C. (Fonseca et al. 2001). With its ability to survive very cold winters, we expect *Oc. japonicus* to spread throughout most of the northern United States and Canada.

The discovery of *Oc. japonicus* in southern Indiana verifies the importance of existing mosquito control and monitoring programs. The selection of natural predators and competitors, elimination of mosquito habitat, and regulation of insects on trade vessels are a few of the many actions being taken to slow the introduction of foreign species. On a local level, public awareness and education are key factors; however, research into the spread of these vectors is of equal importance. Today's unprecedented swift transit of goods has set the stage for the spread and emergence of additional infectious diseases. It is essential, therefore, to research how these mosquitoes disperse and take action to protect our local environments.

## ACKNOWLEDGMENTS

The Clark, Floyd and Harrison County Indiana Health Departments and Indiana University Southeast provided funding for this project. Dr. Claude Baker, Professor of Biology at Indiana University Southeast served as project director and mentor. His help is gratefully acknowledged. We also acknowledge Dr. Dina M. Fonseca of the Smithsonian Institution and the Academy of Natural Sciences who verified the specimens using DNA-sequencing techniques.

## LITERATURE CITED

Andreadis, T.G., J.F. Anderson, L.E. Munstermann, R.J. Wolfe & D.A. Florin. 2001. Discovery, distribution and abundance of the newly introduced mosquito *Ochlerotatus japonicus* (Diptera: Culicidae) in Connecticut, USA. Journal of Medical Entomology 38(6):774–779.

Berry, R. 1999 *Aedes japonicus* B USA (Ohio). International Society for Infectious Diseases. ProMed Mail. Archive 19991022.1897. 2 pp.

CDC. 2001. Embargo on importation of *Dracaena* shipped in standing water. Via the Internet. http://www.cdc.gov/od/oc/media/pressrel/r010702.htm

Fonseca, D.M., S. Campbell, W.J. Crans, M. Mogi, I. Miyagi, T. Toma, M. Bullians, T.G. Andreadis, R.L. Berry, B. Pagac, M.R. Sardelis & R.C. Wilkerson. 2001. *Aedes (Finlaya) japonicus* (Diptera: Culcidae), a newly recognized mosquito in the United States: Analyses of genetic variation in the United States and putative source populations. Journal of Medical Entomology 38(2):135–146.

Linthicum, K.J., V.L. Kramer, M.B. Madon, K. Fujioka & Surveillance-Control Team. 2003. Introduction and potential establishment of *Aedes albopictus* in California in 2001. Journal of the American Mosquito Control Association 19(4): 301–308.

Moore, C.G. & C.J. Mitchell. 1997. *Aedes albopictus* in the United States: Ten-year presence and public health implications. Emerging Infectious Diseases 2(3):329–334.

Peyton, E.L., S.R. Campbell, T.M. Candeletti, M. Romanowski & W.J. Crans. 1999. *Aedes (Finlaya) japonicus japonicus* (Theobald), a new introduction to the United States. Journal of the American Mosquito Control Association 15(2): 238–241.

Sardelis, M.R & M.J. Turell. 2001. *Ochlerotatus j. japonicus* in Frederick County, Maryland: Discovery, distribution, and vector competence for West Nile virus. Journal of the American Mosquito Control Association 17(2):137–141.

Sardelis, M.R., D.J. Dohm, B. Pagae, B. Andre & M.J. Turrell. 2002. Experimental transmission of eastern equine encephalitis virus by *Ochlerotatus j. japonicus* (Diptera: Culicidae). Journal of Medical Entomology 39(3):480–484.

Sardelis, M.R., M.J. Turrell & R.G. Andre. 2003. Experimental transmission of St. Louis encephalitis virus by *Ochlerotatus j. japonicus*. Journal of the American Mosquito Control Association 19(2):159–162.

Scott, J. 2004. *Ochlerotatus japonicus* (Theobald). Rutgers Entomology. NJMCA. New Jersey Mosquito Homepage. Via the Internet. http://www.rci.rutgers.edu/~insects/ocjap.htm

Takashima, I. & L. Rosen. 1989. Horizontal and vertical transmission of Japanese encephalitis virus by *Aedes japonicus* (Diptera: Culicidae). Journal of Medical Entomology 26(5):454–458.

Turell, M.J., M.L. O'Guinn, D.J. Dohm & J.W. Jones. 2001. Vector competence of North American mosquitoes (Diptera: Culicidae) for West Nile virus. Journal of Medical Entomology 38(2):130–134.

Wilson, M.E. 1995. Travel and the emergence of infectious diseases. Emerging Infectious Diseases 1(2):39–46.

*Manuscript received 6 December 2004, revised 2 April 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):65–69

# OBSERVATIONS ON PERIODICAL CICADAS (BROOD X) IN INDIANA AND OHIO IN 2004 (HEMIPTERA: CICADIDAE: *MAGICICADA* SPP.)

**Gene Kritsky**, **Jennifer Webb**, **Michael Folsom**, and **Margie Pfiester**: Department of Biology, College of Mount St. Joseph, Cincinnati, Ohio 45233 USA

**ABSTRACT.** Periodical cicadas belonging to Brood X emerged in parts of western Ohio and throughout most of Indiana in 2004. The first emerging cicadas were found on 9 May. Most areas were reporting emerging cicadas by 14 May, one week earlier than the average historical emergence date of 20/21 May. Average April temperatures were found to predict the day in May when the emergence would begin. The average soil temperature on the morning after the emergence began was 18.3 °C. Periodical cicadas were observed dispersing into areas that had been cleared since the previous emergence. Some periodical cicadas belonging to Brood XIV emerged four years early, joining the eastern edge of Brood X. Approximately 85.3% of the eggs laid in deciduous trees hatched, and some of the nymphs had molted to the second instar by 31 December 2004.

**Keywords:** Periodical cicadas, Brood X, cicadas, Indiana, Ohio

Periodical cicadas belonging to Brood X emerged in May and June 2004 throughout parts of western Ohio and most of Indiana. All three periodical cicada species, *Magicicada septendecim*, *Magicicada cassini*, and *Magicicada septendecula* emerged during the 2004 emergence. This brood last emerged in 1987, when the senior author mapped its distribution in Ohio (Kritsky 1987) and in Indiana with Frank N. Young, Jr. (Young & Kritsky 1988). The oldest historical record of Brood X was made by the Reverend Andreas Sandel, who briefly described its 1715 emergence in Philadelphia (Kritsky 2004). The first record of the brood in Ohio dates to 1817 in Clermont County, east of Cincinnati, and the oldest records in Indiana come from several towns that recorded cicadas in 1834. Indiana, in particular, has an impressive history of periodical cicada studies, with state maps that date back to the 1885 emergence of Brood X. Except for 1953, every Brood X emergence in Indiana since 1885 has been mapped out by entomologists associated with the state (Kritsky 2004).

The emergence of periodical cicadas, like the appearance of a comet, is a predictable phenomenon, which promotes opportunities for experimentation. We planned to look for meteorological factors that would predict when in May the emergence would begin, to map the extent of the brood in Indiana and Ohio, to re-examine the soil temperature as an environmental trigger to initiate the emergence, to assess the effects of clear cutting and replanting during the intervening years between emergences, to determine egg hatch rates, and to check the status of some of the offspring of the 2004 emergence at the end of 2004.

## METHODS

To determine which meteorological factors might predict when in May the emergence would begin, it was necessary to gather weather information from the National Oceanic and Atmospheric Agency for previous emergence years. Newspapers and other observations were scoured to find records that specified the first day of emergence. The meteorological records for those years were used to develop a model to predict the beginning date of the 2004 emergence.

To determine the first day of emergence and to re-examine the work of Heath (1968), who found that periodical cicadas emerge when the soil temperature reaches 17.8 °C, fifteen sites were selected on the campus of the College of Mount St. Joseph and on the grounds of the Sisters of Charity Motherhouse in western Cincinnati. The sites represented a diversity of conditions, including shade/sunlight, degree of slope, and compass orientation. Soil temperature readings (using a digital soil thermometer) and visual surveys for cicada activity were conducted at the sites twice a week from the 31 March to 5 May, and daily from 5 May until the emergence began.

Several approaches were utilized in mapping the statewide distributions of periodical cicadas. Letters and e-mails received from people living in emergence areas provided many data points, which were supplemented by calling county extension agents and state parks to verify that cicadas had been observed. Further information was obtained by driving through emergence areas and recording locations with a global positioning device (GPS). The time-consuming GPS mapping was performed in eastern Cincinnati to determine the eastern boundary of the brood, which will be compared to the western boundary of Brood XIV when that brood emerges in 2008.

To assess the effects of urban development on periodical cicadas, cicada activity was monitored in a recently built housing development, which was cleared of trees for construction in 1994. This site was well within a densely populated Brood X area, with mature woods approximately 400 m away. The development was visited daily during the emergence to determine whether cicadas emerged or dispersed into the area. Cicada choruses in the development were monitored using a RadioShack® digital sound level meter mounted on a tripod.

Egg hatch rates were determined by collecting branches with egg nests in mid-September and carefully removing and counting the eggs. The hatch rate consisted of the number of hatched eggs divided by the total number of eggs found.

Finally, cicada nymphs were excavated in late December 2004 by digging under trees that were heavily scarred by cicada oviposition. The depth to which the nymphs had burrowed was measured using a standard tape measure.

## RESULTS AND DISCUSSION

Heath's (1968) model that periodical cicadas emerge when the soil reaches 17.8 °C suggested that there might be a meteorological predictor that would indicate when a periodical cicada emergence would begin in a given year. Published papers and newspaper accounts going back to 1868 were surveyed to find records that specifically stated on what date an emergence of Brood X or Brood XIV had begun in Cincinnati. Considerable variation was found for the start dates. Exact dates could not be located for many emergence years, but a few were firmly established. In 1885, cicadas started to emerge in Cincinnati on 28 May (Dun 1886). Newspaper reports published in the *Cincinnati Enquirer* provided information about the emergences in 1936, 1940, and 1953. In 1936, the insects started to appear on 19 May, while in 1940 they had not emerged by 1 June; in 1953, however, they started emerging on 18 May. The senior author recorded that the 1987 emergence started on 15 May, and in 1991 it started on 11 May. The average of these first emergence dates sets the historical start of a cicada emergence as 20/21 May.

The emergence start date was compared with the average of April high temperatures, average April low temperatures, and average overall April temperatures for 1936, 1953, 1987, and 1991. Information from 1940 could not be used because a precise emergence date could not be established for that year, and no accurate temperature readings were available for 1885. A high correlation was found between average April temperatures and the emergence date ($R^2 = 0.99$). The formula determined to predict the beginning of a cicada emergence was $E = (19.465 - t)/0.5136$, where $E$ = emergence start date in May and $t$ = average April temperatures in °C.

The emergence formula was used to predict that the 2004 emergence would start on 14 May, nearly a week earlier than the historical average. Figure 1 shows how the emergence began in 2004. The first cicadas were observed at one of the 15 monitoring sites on 9 May. On 12 May, three locations had evidence of emerging cicadas. Twenty-four hours later, six of 15 sites had cicada emergences. On 14 May, cicadas had emerged at 80% of the sites. All the stations had emerging cicadas by 17 May. Thereby, showing that the formula can effectively be used to predict a narrow range of dates during which an emergence will begin.

Such information is important to homeowners, gardeners, city parks, and arboreta. Those individuals, wanting to protect their trees from

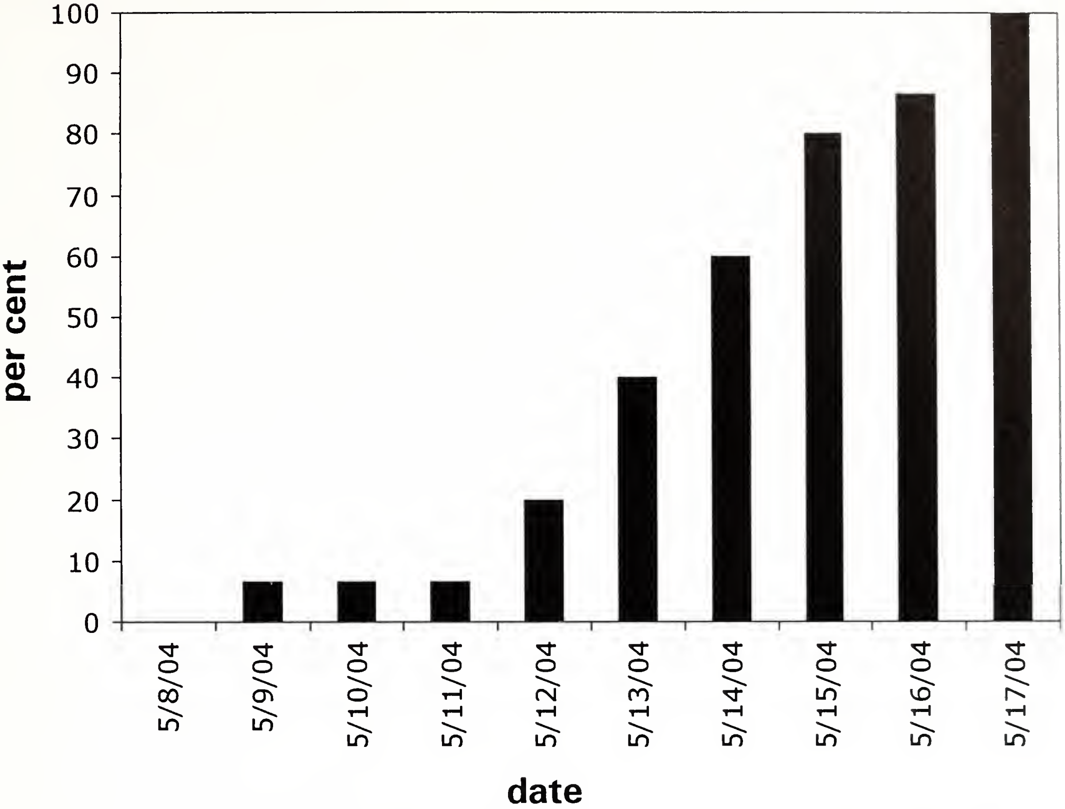


Figure 1.—The 2004 emergence of periodical cicadas started on 9 May and was widespread by 17 May.

damage, may wrap the young trees with lightweight fabric to prevent the cicadas from ovipositing on the terminal branches. However, care should be taken not to keep the trees wrapped for too long, as this may block sunlight and limit the trees' growth. When our prediction was announced to the public on 1 May, those who needed to protect their trees were given the opportunity to plan when at-risk trees should be wrapped.

The College of Mount St. Joseph Cicada Watch website received over 900 e-mails from Indiana and Ohio. Moreover, county extension offices from every county where periodical cicadas had emerged in the past were contacted to verify if cicadas had emerged in 2004. Periodical cicadas were reported from 82 counties in Indiana and 28 counties in Ohio. A map of the county distribution is presented in Fig. 2. The heaviest numbers of cicadas were reported in southwestern Ohio and throughout southern Indiana. In southwestern Ohio, the eastern edge of Brood X was found to be approximately 1600 m west of Point Pleasant along the Ohio River. The boundary ran north to Clertoma and extended northwestward to Symmes Township, where it continued on a northern transect.

Areas in Madeira, which experienced dense Brood XIV cicada populations in 1991, had a moderate emergence this year. Trees that were planted after 1987 (when Brood X last emerged) but before the 1991 emergence of Brood XIV were found to have cicada skins and holes at their bases. These cicadas were Brood XIV cicadas that had accelerated to emerge four years early. This phenomenon is the scenario that Kritsky (2004) presented to explain how broods might change in distribution over time. The area will be surveyed again in 2008, when Brood XIV will next emerge, to determine the extent of overlap between the two broods. Smaller pockets of accelerating cicadas were also reported in Ohio's West Union in Adams County and in Chillicothe in Ross County.

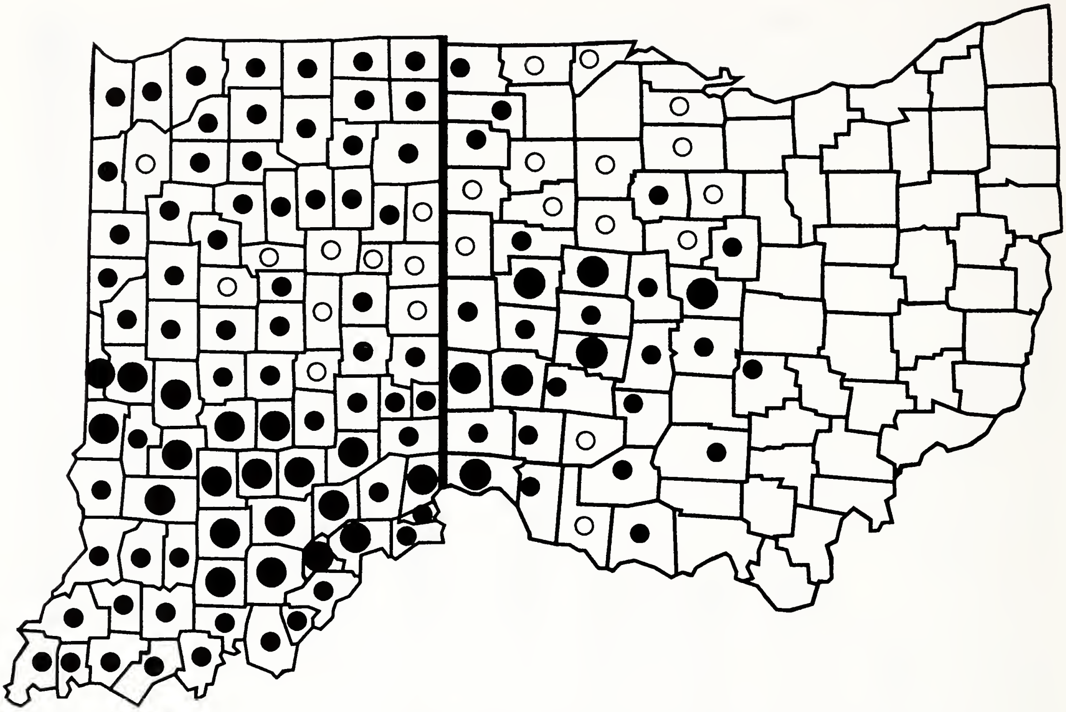


Figure 2.—The Indiana and Ohio distribution of periodical cicadas in 2004. The large circles represent counties reporting dense populations, smaller circles represent counties with isolated pockets of periodical cicadas, and open circles represent counties where cicadas had been reported in the past, but apparently did not emerge during 2004.

Heath's (1968) model that cicadas emerge when the soil temperature reaches 17.8 °C was re-examined by taking soil temperature readings between 1000 h and 1200 h at each of our 15 study sites. The soil temperatures on the first day of cicada emergence ranged from 16.6 °C to 20.1 °C with an average temperature of 18.3 °C. This supports Heath's 1968 study that periodical cicadas have a temperature threshold of approximately 17.8 °C that aids in triggering the mass emergence. As Heath (1968) reported, we also found that cicadas emerged first from south-facing locations in full sun.

No cicadas emerged under any of the trees in the housing development that was monitored. However, by the last week of May, periodical cicadas had dispersed into the area from mature trees no closer than 400 m away, and they formed chorusing centers that were measured at sound levels up to 96 dB. Oviposition in the development was very high, which promises a large emergence in 2021.

The loudness of a mixed species chorus depended on the distance between the sound level meter and the chorus. When sound level of a single chorus was measured at various distances, it was found that the loudness decreased by approximately 2 dB for every 3.05 m of distance between the chorus and the measuring device (Fig. 3). This relationship may provide an estimate of the loudness of a chorus when measuring distant trees.

The cicada eggs began to hatch in late July. Egg nests from ginkgo, red oak, and American linden were examined; and a hatch rate of approximately 85.3% was established for eggs laid in branches that had not broken or wilted. Egg nests from flagged branches yielded egg hatch rates of 47.2% ($n$ = 301) in red oak and 48.3% ($n$ = 302) in American linden. White (1981) found that the number of eggs that die in flagged branches depended on how long the branch remained alive after oviposition. The longer the branch remained alive the greater the hatch rate.

Periodical cicadas nymphs, hatched from the eggs laid during the 2004 emergence, were

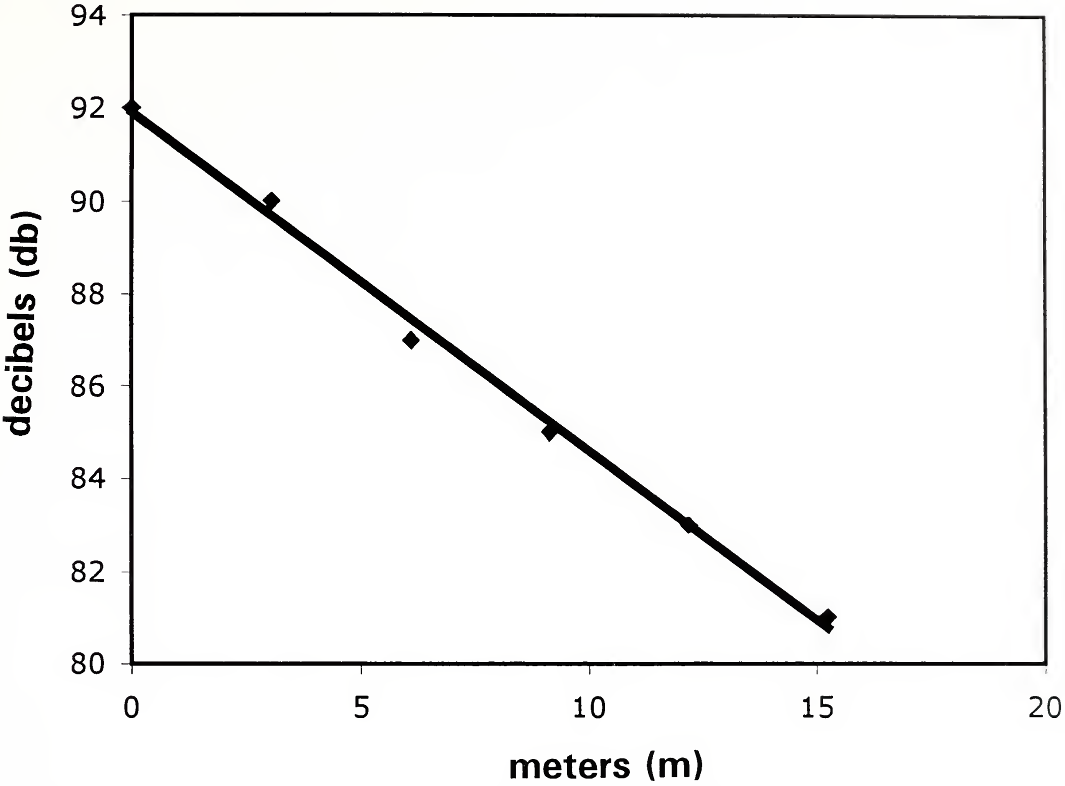


Figure 3.—Decline in periodical cicada chorus loudness when measured at increasing distances. The sampled chorus was composed primarily of *Magicicada cassini.*

excavated on 31 December 2004. The nymphs were found between 16.5 and 28 cm deep below the topsoil and in the uppermost clay layer, which places them below the freeze line of the area. Both first and second instar nymphs were found, indicating that many had molted to the second instar within five months after hatching.

## ACKNOWLEDGMENTS

We thank the Ohio Biological Survey and Ace Pest Control for financial support of the mapping project. We also thank Robert Waltz and Gala Erland for help with contacting county agents, Christopher Buelterman for his help with the thousands of e-mails, and Jessee Smith for designing the College of Mount St. Joseph Cicada Watch Website and reviewing this manuscript. We also thank Robert Waltz, James Curry, and James Berry for their valuable suggestions that improved this manuscript. Thanks are also due to the thousands of people who sent us their observations of the 2004 emergence.

## LITERATURE CITED

Dun, W.A. 1886. Observations on the periodical cicada. Journal of the Cincinnati Society of Natural History 8:233–234.

Heath, J.E. 1968. Thermal synchronization of emergence in periodical "17-year" cicadas (Homoptera. Cicadidae, *Magicicada*). American Midland Naturalist 80:440–448.

Kritsky, G. 1987. The 1987 emergence of the periodical cicada (Homoptera: Cicadidae: *Magicicada* spp.: Brood X) in Ohio. Ohio Journal of Science 88:168–170.

Kritsky, G. 2004. Periodical Cicadas: The Plague and The Puzzle. Indiana Academy of Science. Indianapolis, Indiana.

White, J. 1981. Flagging: Host defences versus oviposition strategies in periodical cicadas (*Magicicada* spp. Cicadidae, Homoptera) Canadian Entomologist 113:727–738.

Young, F.N. & G. Kritsky. 1988. Observations on periodical cicadas (Brood X) in Indiana in 1987 (Homoptera: Cicadidae). Proceedings of the Indiana Academy of Science 97:323–329.

*Manuscript received 17 February 2005, revised 2 May 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):70–72

# NOCTURNAL BEHAVIOR AND ROOSTING ECOLOGY OF A JUVENILE *LASIURUS CINEREUS* NEAR INDIANAPOLIS, INDIANA

**Dale W. Sparks**: Department of Ecology and Organismal Biology, Indiana State University, Terre Haute, Indiana 47809 USA

**Christopher M. Ritzi**: Department of Biology, Sul Ross State University, Alpine, Texas 79832 USA

**Brianne L. Everson**: Department of Ecology and Organismal Biology, Indiana State University, Terre Haute, Indiana 47809 USA

**ABSTRACT.** A juvenile male hoary bat (*Lasiurus cinereus*) was radio-tracked to day roosts and foraging areas within an undeveloped area in suburban Indianapolis. The bat roosted with two other bats, likely a mother and sibling, in large eastern cottonwoods (*Populus deltoides*). It used a small foraging area (21.5 ha) and spent much time foraging in oldfields. Observations of this, and several untagged bats, lead us to hypothesize these behaviors are normal for hoary bats in Indiana.

**Keywords:** Hoary bat, *Lasiurus cinereus*, foraging, Indianapolis International Airport, roosting

A long-term study of the bat community is being conducted near the developing edge of Indianapolis, Indiana (Sparks et al. 1998; Whitaker et al. 2004). The largest bat in this community is the hoary bat (*Lasiurus cinereus*), which is infrequently captured during mist-net surveys. Acoustic data from another regional metroplex (Chicago, Illinois), however, suggest hoary bats are more common than netting would indicate (Gehrt & Chelsvig 2004). In addition to being large, hoary bats occasionally attack other bats (Bishop 1947; Orr 1950; Bell 1980), and defend territories during inclement weather (Barclay 1986, 1989). As such, hoary bats, even at low densities, may be an important component of the local community.

Detailed data about the nocturnal behavior of hoary bats are limited to studies conducted in British Columbia (Barclay 1986, 1989). No information about foraging and roosting behavior of this species is available in Indiana (Mumford & Whitaker 1982), where the species appears to be in decline (Whitaker et al. 2002). In 2003 three hoary bats were radio-tagged, and one of these was successfully tracked to both its foraging and roosting habitat near the Indianapolis International Airport. The behavior of this bat differed substantially from that reported for adult females in more pristine habitats in British Columbia (Barclay 1986, 1989). The primary purpose of this paper is to present a summary of the roosting and foraging behavior of this bat.

## METHODS

The focal animal for this study was captured on 13 July 2003 while an annual mist-net survey of the airport's conservation properties was being conducted. This netting survey was targeted at obtaining Indiana myotis (*Myotis sodalis*) for telemetry, with data from this study used to direct local conservation efforts (Sparks et al. 1998, in press; Whitaker et al. 2004). Once detailed telemetry studies have begun, additional individuals or species can be added to the study for the cost of their radio tags (pers. obs.). Upon capture, this bat was examined for age, sex, reproductive status, parasite load, and general condition. A lipped aluminum band was placed on the right wing (Lambourne's Lmt., Birmingham, United Kingdom), a small patch of fur in the midscapular area was shaved, and a 0.49 g radio transmitter (model LB-2, Holohil Systems Ltd., Carp, Ontario, Canada) was attached to the back of the bat using colostomy glue (Skin-bond, Smith and Nephew, Largo, Florida, USA). The 5% ratio of transmitter-to-body weight recommended by Aldridge & Brigham (1988) was not violated. Similar techniques were used to mark two other hoary bats captured in 2003, but both left the study area within 24 hours. We suspect these bats were migrating because eastern red bats (*Lasiurus borealis*) captured during the same time period were also migrating (B.L. Everson unpubl. data).

The radio-tagged hoary bat was tracked from 14 July until the signal from the transmitter was no longer detected (22 July). Each afternoon the bat was tracked to a day roost. Day roosts were used as starting points for foraging studies conducted from 14–17 July. Beginning with the departure of the bat from the roost, 3–7 tracking crews used three-element yagi antennas and hand-held compasses to simultaneously obtain estimates of the azimuth from the location of each tracking crew to the bat. Azimuths were recorded every 6–9 minutes (depending on the number of other bats being concurrently tracked), and tracking continued until the bat roosted. These telemetry azimuths were then converted to point data using the computer program Locate II (Nams 2000). Point data were loaded into a Geographic Information System (GIS, Arc View, ESRI Corporation 1999), where they were overlaid on a Digital Ortho Quarter Quadrangle photographic map (US Geological Survey 1998); and a habitat map that was digitized from the photomap and ground-checked to include recent habitat changes. A home range (minimum convex polygon) was created surrounding 95% of the foraging points.

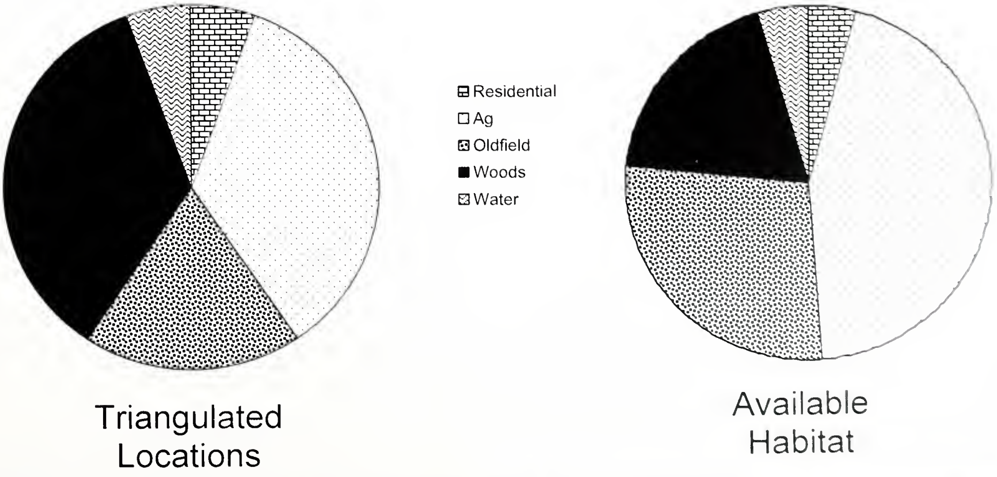
Table 1.—Characteristics of roost trees used by a juvenile hoary bat near Indianapolis, Indiana, in July 2003.

| Tree species | Height (m) | Diameter (cm) | Dates of use |
|---|---|---|---|
| *Populus deltoides* | 31 | 94 | 14–15 July |
| *Populus deltoides* | 38 | 84 | 16–17 July |
| *Populus deltoides* | 35 | 94 | 18–19 July |

## RESULTS

The bat was tracked to three roost trees in eight days (Table 1). All roosts were large eastern cottonwoods (*Populus deltoides*), where the bat roosted with two other bats (presumably the mother and a sibling). It was not possible to verify the exact location of the day roost on most days. However, on 16–17 July, the group of three roosted in live foliage on a south-facing limb 27 m above the ground. On other days, radio-telemetry indicated that roosting occurred high in trees, although specific roosts could not be observed. During 2003, several untagged hoary bats were observed using similar roosts, suggesting these observations near Indianapolis are typical of this species in Indiana.

During four nights of foraging, 59 triangulations on this bat were obtained, and 57 of



Triangulated Locations

Available Habitat

Figure 1.—Comparison of triangulated positions relative to proportions of habitat within the home range of a juvenile male hoary bat (*Lasiurus cinereus*), radio-tracked near Indianapolis, Indiana, in July 2003.

these triangulations were included in the home range. The bat foraged for an average of 107 min per night (range 54–155 min), and returned to the area where it day-roosted following each foraging bout. Although a second foraging bout was detected on 17 July, it lasted only 9 min. The focal bat had a home range containing only 21.5 ha, and flew no further than 1.2 km from any roost. Open habitats including oldfields and agricultural fields were extensively used for foraging, and habitat use was broadly similar to habitat available within the home range (Fig. 1).

## DISCUSSION

The small size of the foraging range for this bat was surprising. Given the wing morphology of this species (Farney & Fleharty 1969; Aldridge & Rautenbach 1987) and previously published observations of conspecifics in British Columbia (Barclay 1989), it was anticipated that it would be necessary to follow this bat throughout much of suburban Indianapolis. Barclay (1989) tracked adult females as far as 20 km from their roosts. It is possible our results are spurious or the result of tracking only a single juvenile. We suspect that this is not the case for two reasons. First, we concurrently tracked 11 congeneric red bat (*Lasiurus borealis*), which also have small home ranges (mean = 68 ha, range = 28–143 ha) at the Indianapolis International Airport (B.L. Everson unpubl. data). Second, the hoary bat roosted in riparian vegetation along a stream (East Fork of White Lick Creek) in an area surrounded by fields. Thus, suitable foraging and roosting habitats were located in close proximity.

Hoary bats can be effectively tracked to their foraging ranges using radio-telemetry, but complete analysis of habitat use by animals requires large sample sizes and is labor intensive. Rarely-captured taxa, such as the hoary bat in Indiana, are often ignored by researchers because of the difficulty in obtaining meaningful data, but such species should not be overlooked purely because they are difficult to capture.

## LITERATURE CITED

Aldridge, H.D.J.N. & R.M. Brigham. 1988. Load carrying and maneuverability in an insectivorous bat: A test of the 5% "rule" of radio-telemetry. Journal of Mammalogy 69:379–382.

Aldridge, H.D.J.N. & I.L. Rautenbach. 1987. Morphology, echolocation and resource partitioning in insectivorous bats. Journal of Animal Ecology 56:763–778.

Barclay, R.M.R. 1986. Foraging strategies of silver haired (*Lasionycteris noctivagans*) and hoary (*Lasiurus cinereus*) bats. Myotis 23/24:161–166.

Barclay, R.M.R. 1989. The effect of reproductive condition on the foraging behavior of female hoary bats, *Lasiurus cinereus*. Behavioral Ecology and Sociobiology 24:31–37.

Bell, C.P. 1980. A possible case of interspecific transmission of rabies in insectivorous bats. Journal of Mammalogy 61:528–530.

Bishop, S.C. 1947. Curious behavior of a hoary bat. Journal of Mammalogy 28:293–294.

Farney, J.P. & E.D. Fleharty. 1969. Aspect ratio, loading, wing span, and membrane areas of bats. Journal of Mammalogy 50:362–367.

Gehrt, S.D. & J.E. Chelsvig. 2004. Species-specific patterns of bat activity in an urban landscape. Ecological Applications 14:625–635.

Mumford, R.E. & J.O. Whitaker, Jr. 1982. Mammals of Indiana. Indiana University Press. Bloomington, Indiana.

Nams, V. 2000. Locate II. Version 1.81. Truro, Nova Scotia, Canada.

Orr, R.T. 1950. Unusual behavior and occurrence of a hoary bat. Journal of Mammalogy 31:456–457.

Sparks, D.W., J.A. Laborda & J.O. Whitaker, Jr. 1998. Bats of the Indianapolis International Airport as compared to a more rural community of bats at Prairie Creek. Proceedings of the Indiana Academy of Science 107:171–179.

Sparks, D.W., C.M. Ritzi, J.E. Duchamp & J.O. Whitaker, Jr. *In press*. Foraging ecology of Indiana myotis at an urban/rural interface. Journal of Mammalogy.

Whitaker, J.O., Jr., V. Brack, Jr. & J.B. Cope. 2002. Are bats in Indiana declining? Proceedings of the Indiana Academy of Science 111:95–106.

Whitaker, J.O., Jr., D.W. Sparks & V. Brack, Jr. 2004. Bats of the Indianapolis International Airport Area, 1991–2001. Proceedings of the Indiana Academy of Science 113:151–161.

*Manuscript received 20 November 2004, revised 14 February 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):73–76

# BAT COMMUNITIES IN HIGHLY IMPACTED AREAS: COMPARING CAMP ATTERBURY TO THE INDIANAPOLIS AIRPORT

**Wade A. Ulrey**[1], **Dale W. Sparks**, and **Christopher M. Ritzi**[2]: Department of Ecology and Organismal Biology, Indiana State University, Terre Haute, Indiana 47809 USA

**ABSTRACT.** Little information is available about how bats respond to landscape-scale disturbances. Herein is presented a comparison of two distinct forms of managed lands. Camp Atterbury is an active military training area near Edinburgh, Indiana. It is subject to human disturbances such as live fire weapons exercises and troop movements; however, its forested habitats are relatively intact. In contrast, the Indianapolis International Airport conservation area is a much more developed and patchy habitat along the developing edge of suburban Indianapolis. During 2002, mist-net surveys were conducted at both sites, capturing the same seven species. Species associated with buildings (big brown bat, *Eptesicus fuscus*; and little brown myotis, *Myotis lucifugus*) were more commonly captured at the airport, whereas at Camp Atterbury, the forest-dwelling northern myotis (*Myotis septentrionalis*) was captured more often.

**Keywords:** Bats, Indiana, Camp Atterbury, Indianapolis International Airport, managed lands

Conservation activities aimed at North American bats are hampered by a lack of understanding of how bats respond to different land-use practices (Kurta & Teramino 1992; Sparks et al. 1998; Pierson 1998; Miller et al. 2003; Sparks 2003). This paper compares the bat fauna of an active military reservation, Camp Atterbury Joint Maneuver Training Center, to the bat fauna of properties managed for conservation by the Indianapolis International Airport. These areas are both located in central Indiana (Fig. 1). Forests of this region are dominated by oak-hickory, beech-maple and bottomland hardwood forest complexes (Kiser 2002). Management of federally-endangered Indiana myotis (*Myotis sodalis*) is one of the goals at both of these properties.

**Study areas.**—Both Camp Atterbury and the airport are heavily impacted by human disturbance. Camp Atterbury encompasses 13,408 ha, located approximately 56 km south of Indianapolis, in parts of Bartholomew, Brown, and Johnson counties (Kiser 2002). It is an active military facility managed primarily for military training, including live fire exercises involving weapons ranging from small arms to 155 mm howitzers, and battalion-scale troop maneuvers. The approximately 10,719 ha of forest on the facility are managed for a variety of activities including: commercial timber harvest, wildlife habitat protection, watershed protection, recreation, and aesthetics (Watson 1997). The remaining land cover consists of mowed fields, old fields, early successional shrubby uplands, wetlands, roads, parking lots, barracks, and other anthropogenic structures.

The Indianapolis International Airport conservation properties are at the southwestern edge of the Indianapolis metropolitan area in Hendricks and Marion counties (Sparks et al. 1998; Sparks 2003; Whitaker et al. 2004). Habitats consist primarily of numerous small woodlots surrounded by a matrix of agricultural fields in the south and neighborhoods and commercial properties in the north. A narrow (approximately 30 m wide) riparian forest occurs along the banks of the East Fork of White Lick Creek, a medium-sized perennial stream that bisects the study area. The airport study area is transversed by numerous small roads and four multi-lane divided highways.

## METHODS

Results of mist-net surveys conducted at pre-existing sites on both areas during June

---

[1] *Present Address:* Archbold Biological Station, 123 Main Drive, Venus, Florida 33960 USA

[2] *Present Address:* Department of Biology, Sul Ross State University, Alpine, Texas 79832 USA

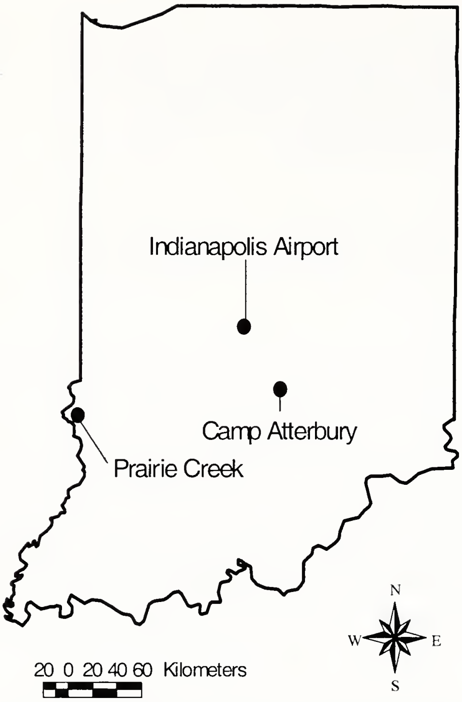


Figure 1.—Locations of the study sites at Camp Atterbury, the Indianapolis Airport, and Prairie Creek.

and July of 2002 were compared. Fifteen stations were netted a total of 23 times at Atterbury, and 10 stations were netted a total of 19 times at the airport. Surveys were conducted approximately three times per week. Nine days was the shortest interval between consecutive nettings at an individual site. No station was sampled more than three times. Netting stations were placed along flyways created by forest openings associated with water sources such as ponds, road ruts, and (most frequently) streams. A net night was defined as one station surveyed, with two multitier 9 m mist-nets used in such a way as to maximize the amount of flyway covered. Netting at both sites was conducted throughout available management areas, except the "impact area" at Camp Atterbury. This area is targeted during live-fire exercises and is unsafe to enter due to potential unexploded ordnance. Surveys at both sites are part of larger research programs, and thus only data collected when both areas were being sampled simultaneously were analyzed.

For each captured bat the species, sex, reproductive class (Racey 1988), and age (Anthony 1988) were determined. Each bat was also weighed, banded with a uniquely-numbered tag, examined for parasites, and measured for right forearm length. A series of Mann-Whitney *U* tests was used to compare the number of each species captured per night at the airport to number of that species captured per net night at Camp Atterbury. The average species richness (defined as number of species caught per night for each site) was compared, and the abundance of bats (i.e., total number of bats per net night) was determined. All statistical analyses were performed using SPSS 11.5 for Windows, Standard Version with a rejection level of $\alpha = 0.05$.

## RESULTS

In 23 net nights 106 bats were captured at Atterbury, compared to 103 bats in 19 net nights at the airport. The same seven species were caught at the two study areas, but their abundances differed substantially between the two sites (Table 1). Two species (big brown bat, *Eptesicus fuscus*; and little brown myotis, *Myotis lucifugus*) that are commonly associated with buildings were significantly more common at the airport (56 *E. fuscus* and 14 *M. lucifugus* captured) than at Camp Atterbury (18 *E. fuscus* and 2 *M. lucifugus* captured). Conversely, the forest-dwelling northern myotis (*Myotis septentrionalis*) was more prevalent at Camp Atterbury (27 captured, versus 3 captured at the airport). No significant difference was found in the capture rates of Indiana myotis, red bat (*Lasiurus borealis*), evening bat (*Nycticeius humeralis*), or eastern pipistrelle (*Pipistrellus subflavus*). The mean number of bats per net night was similar at either site (4.609 for Camp Atterbury, and 5.421 for the airport, $U = 199.5$, $P = 0.629$), as was mean species richness (2.435 for Camp Atterbury, and 2.790 for the airport, $U = 190.5$, $P = 0.472$).

## DISCUSSION

Despite markedly different landscapes, bat communities of Camp Atterbury and the airport are similar. During this study we recorded the same seven species at both sites, and found significant differences in capture rates for only three species. Both the big brown bat and the little brown myotis commonly roost in structures such as buildings and bridges

Table 1.—Bats captured in mist-netting surveys of Camp Atterbury Joint Maneuver Training Center and the Indianapolis International Airport conservation properties.

| Site: | Camp Atterbury | | Airport | | | |
|---|---|---|---|---|---|---|
| Net nights: | 23 | | 19 | | | |
| Bat species | Number of bats | Bats caught per night | Number of bats | Bats caught per night | $U$ | $P$ |
| *Eptesicus fuscus* | 18 | 0.783 | 56 | 2.947 | 113.0 | 0.005 |
| *Lasiurus borealis* | 27 | 1.174 | 11 | 0.579 | 170.0 | 0.184 |
| *Myotis lucifugus* | 2 | 0.087 | 14 | 0.737 | 118.5 | 0.001 |
| *Myotis septentrionalis* | 27 | 1.174 | 3 | 0.158 | 131.5 | 0.010 |
| *Myotis sodalis* | 6 | 0.261 | 9 | 0.474 | 186.0 | 0.298 |
| *Nycticeius humeralis* | 8 | 0.348 | 2 | 0.105 | 192.0 | 0.301 |
| *Pipistrellus subflavus* | 18 | 0.783 | 8 | 0.421 | 205.0 | 0.689 |
| Total | 106 | 4.609 | 103 | 5.421 | 199.5 | 0.629 |

(Whitaker & Hamilton 1998). Due to the greater density of such structures, higher capture rates of these species would be expected at the airport.

We were, however, surprised that only northern myotis were more commonly captured at Camp Atterbury. Camp Atterbury is primarily forested, and as such, it is presumed that it would provide high quality habitat for forest species. We suspected that federally-endangered Indiana myotis and state-endangered evening bats would be more common at Camp Atterbury. In similar work, both these species and northern myotis were less frequently captured at the airport than at a more pristine area (Fig. 1) along Prairie Creek in Vigo County, Indiana (Sparks et al. 1998). These results were interpreted at the time as indicating that these three species were particularly susceptible to forest destruction and fragmentation. However, at Camp Atterbury, only northern myotis were more frequently captured. We suspect that this difference is the result of two factors. First, Camp Atterbury is intermediate in forest content and connectivity between the airport and Prairie Creek. Second, mist-net surveys are affected by many factors, particularly location of roosts. Since data used in the airport/Prairie Creek comparison were collected, both evening bat and Indiana myotis roosting locations have moved closer to netting locations at the airport, and consequently both bats are being captured more frequently now than in the past (Whitaker et al. 2004). At Camp Atterbury, conversely, most evening bat roosts were located outside the base, while many Indiana myotis roosts were located within the impact area, which we were unable to survey (Whitaker & Gummer 2002). Given the short foraging ranges of evening bats (Duchamp et al. 2004), it is also likely many evening bats roosting within the impact area never reached netsites.

At both Camp Atterbury and the airport, managers are challenged with conserving bats in habitats primarily used for other purposes. These two areas provide an important opportunity to explore effects of management activities on bats at multiple levels. Of particular interest would be behavioral studies aimed at determining how bats respond to unusual disturbances present at the two sites. For Camp Atterbury, this would include responses of bats to military exercises. At the airport, efforts should be targeted at examining interactions between bats and development.

## ACKNOWLEDGMENTS

Funding and logistical support were provided by the Military Department of Indiana and the Indianapolis Airport Authority. Field assistance was provided by B.L. Everson, B.J. Foster, C.L. Gummer, S.L. Gummer, S.S. Nard, C.L. Roever, J.J. Sheets, R. Wickens, and K.S. Williams. C.L. Roever, along with J.O. Whitaker, Jr. and M. Brethauer, also read and improved earlier drafts of the manuscript. Work on Camp Atterbury would not have been possible without the assistance of A. Howard, who coordinated our netting efforts with the military staff. All methods used herein were approved by the Indiana State University Committee on Animal Care and Use (Protocol #DS/JW 02/19).

## LITERATURE CITED

Anthony, E.L.P. 1988. Age determination in bats. Pp. 47–58, *In* Ecological and Behavioral Methods for the Study of Bats. (T.H. Kunz, ed.). Smithsonian Institution Press, Washington, D.C. 533 pp.

Duchamp, J.E., D.W. Sparks & J.O. Whitaker, Jr. 2004. Foraging habitat selection by bats at an urban-rural interface: Comparison between a successful and a less successful species. Canadian Journal of Zoology 82:1157–1164.

Kiser, J.D., J.R. MacGregor, H.D. Bryan & A. Howard. 2002. Use of concrete bridges as night-roosts. Pp. 208–215, *In* The Indiana Bat: Biology and Management of an Endangered Species. (A. Kurta & J. Kennedy, eds.). Bat Conservation International, Austin, Texas.

Kurta, A. & J.A. Teramino. 1992. Bat community structure in an urban park. Ecography 15:257–261.

Miller, D.A., E.B. Arnett & M.J. Lacki. 2003. Habitat management for forest-roosting bats of North America: A critical review of habitat selection. Wildlife Society Bulletin 31:30–44.

Pierson, E.D. 1998. Tall trees, deep holes, and scarred landscapes: Conservation biology of bats in North America. Pp. 309–324, *In* Bat Biology and Conservation. (T.H. Kunz & P.A. Racey, eds.). Smithsonian Institution Press. Washington, D.C.

Racey, P.A. 1988. Reproductive assessment of bats. Pp. 31–45, *In* Ecological and Behavioral Methods for the Study of Bats. (T.H. Kunz, ed.). Smithsonian Institution Press, Washington, D.C. 533 pp.

Sparks, D.W. 2003. How does urbanization impact bats? Ph.D. dissertation, Indiana State University, Terre Haute.

Sparks, D.W., J.A. Laborda & J.O. Whitaker, Jr. 1998. Bats of the Indianapolis International Airport as compared to a more rural community of bats at Prairie Creek. Proceedings of the Indiana Academy of Science 107:171–179.

Watson, M. 1997. Survey of bat species: Atterbury Reserve Forces Training Area, Edinburgh, Indiana. Technical report for Military Department of Indiana.

Whitaker, J.O., Jr. & C.L. Gummer. 2002. Bats of Camp Atterbury, with emphasis on roosting of Indiana myotis and evening bats 2002. Technical report for Military Department of Indiana.

Whitaker, J.O., Jr. & W.J. Hamilton, Jr. 1998. Mammals of the Eastern United States. 3rd Edition. Cornell University Press, Ithaca, New York. 583 pp.

Whitaker, J.O., Jr., D.W. Sparks & V. Brack, Jr. 2004. Bats of the Indianapolis International Airport area, 1991–2001. Proceedings of the Indiana Academy of Science 113(2):151–161.

*Manuscript received 3 October 2004, revised 10 February 2005.*

2005. Proceedings of the Indiana Academy of Science 114(1):77–81

# MINUTES OF THE MEETINGS OF THE INDIANA ACADEMY OF SCIENCE

# 2004

## COMBINED MEETING OF THE EXECUTIVE COMMITTEE AND THE COUNCIL

Hanover College
16 April 2004

President Don Ruch called the meeting to order at 2:12 PM. Attending: President-Elect Uwe Hansen, Secretary Nils I. Johansen, Executive Director Nelson Shaffer, Editor of the *Proceedings* Jim Berry, Librarian Holly Oster, History of Science Section Chair Dick Conklin, Historian/Necrologist William R. Gommel, AAAS Representative and Chair of Chemistry Section Richard Kjonaas, Programs and Invitations Committee Chair David Daniell, Academy Foundation Representative Frank A. Guthrie, Biodiversity Committee Chair Richard H. Maxwell, Publications Chair Bill McKnight, Natural Resources Committee Representative Damian Schmelz, and Geology & Geography Section Chair Walter A. Hasenmueller, and Dan Webster.

**Approval of Agenda.**—There was unanimous approval.

**Approval of Minutes of Fall 2003 Meeting.**—The amended minutes were approved.

### Individual Reports

**Treasurer's report.**—Ed Frazier was absent, and a written report was presented.

**Executive Director's report.**—Nelson Shaffer reported that there were 716 members at this time. Following a report on trends in the membership, it was suggested that the membership receive e-mail reports from IAS activities and that the Secretary could do this as part of the duties of that office. It was also suggested that the Secretary should send minutes of past Executive Committee meetings to the committee prior to the next meeting. Discussion followed, but no action was taken.

***Proceedings* Editor's report.**—Jim Berry reported that reprints can now be downloaded. A question from the floor asked if the *Proceedings* should be available on line. Discussion ensued, and the consensus was that the abstracts could be on-line, but not the *Proceedings*. The Table of Contents could be online; however, it should be put on the website. Jim Berry will contact Marcia Moore about this.

**Newsletter Editor's report.**—Uwe Hansen made a report, and he requested that the membership submit items for the newsletter. The newsletter is within budget. The deadline for the June newsletter is 15 May. Hansen solicited pictures from tomorrow's fieldtrips for the newsletter. Don Ruch will be the newsletter editor next (2005) year.

**Secretary's report.**—Nils Johansen had no additional report.

**President-Elect's report.**—Uwe Hansen presented a proposal for a Technical Council that will be a later item on the agenda and will be discussed at that time.

**President's report.**—Don Ruch reported that all committee Chairs have been filled except the Youth Activities Chair. An *ad-hoc* committee chaired by Melissa Werner is working on finding a replacement. We will come back with related items (Section Structure and the Implementation of Scientific Presentation Rubric for Evaluation of Student Presentations at the Annual Meeting) under the "New Business" portion of the agenda. The Executive Committee of IAS will look further into advertising in Academy publications by corporate members. He charged the Section Chairs to send a description of the Section to Marcia Moore (web-master) and amend it after the Fall Section business meeting if necessary. The Audit Report was attached to the minutes.

### Committee Reports

**Academy Foundation.**—Frank Guthrie submitted a written report.

**Research Grants.**—Nelson Shaffer gave an oral report in the Chair's absence. The committee has selected 17 grant recipients.

**Programs, Invitations and Local Arrangements.**—David Daniell reported that the 2004 Fall Meeting will be at Hanover College on 28–29 October 2004. Abstract deadline will be 1 September 2004. The 2005 meeting location will be St. Mary-of-the-Woods College. The Spring meeting will be mid-April, the Fall meeting in mid-October. The exact dates will follow. The 2006 meeting location will be Ball State University. The tentative 2007 meeting location will be the University of Southern Indiana or the University of Evansville. There was a tentative suggestion for a 2006 meeting at Indiana University Bloomington. Discussion followed on the timing of the Fall Meeting, the availability of the abstracts, and the timing of the Fall Meeting with the institution's Fall Break. No action was taken.

**Nominations.**—No report.

**Publications.**—Bill McKnight gave an oral report on the current status of Academy publications and progress towards publication date.

**Finance.**—The Audit Report was attached to the minutes.

**Resolutions.**—A resolution thanking the host institution for the Spring and Fall Meeting will be presented at the Fall 2004 meeting.

**Youth Activities.**—No report. A search for a Chair is under way.

**Library and Archives.**—Holly Oster gave an oral report. Academy *Proceedings* currently take up 9.5 feet of shelf space. The Library lobby has a display on the Lewis and Clark Expedition. The Research Grants Committee now sends approved grants to Oster for archiving. Uwe Hansen publicly thanked Holly for her work, and a round of applause followed.

**Amendments.**—Uwe Hansen reported the Amendments Committee recommended the following for consideration at this (Spring 2004) meeting with a vote scheduled for the Fall 2004 Meeting. Under Bylaws, Article XI, Rules of Procedure, add the following two sections:

Section 2. Actions requiring the vote of any committee are taken at any duly constituted meeting of the committee, or in response to a mail or electronic ballot. Unresolved concerns about actions submitted for mail or electronic balloting are remanded to a formal meeting of the committee.

Section 3. A majority affirmative vote of the Council authorizes actions. The participation of a quorum (see Constitution: Article VI, Section 2) is required for the vote. Such a vote can be taken at a duly constituted meeting of the Council or by mail or electronic ballot.

**Awards.**—No report.

**Biodiversity and Natural Areas.**—No report. The committee has not yet met.

**Junior Academy and Talent Search.**—No report. A question was raised if the Youth Activities committee and the Junior Academy should be merged. No conclusion.

**Web-site.**—Marcia Moore submitted a written report; and in her absence Nelson Shaffer commented on the report.

**Speaker of the Year.**—No report.

**Natural Resources Commission.**—Damian Schmelz, IAS Representative to the Commission, submitted a written report.

**AAAS.**—IAS Representative to the AAAS Richard Kjonaas submitted a written report. No resolutions were passed by AAAS.

**Historian/Necrologist.**—Bill Gommel reported the passing of four members since the Fall 2003 meeting: Maud Ora Lang and three past presidents of the Academy; Wilton N. Melhorn, Howard R. Youse, and William B. Hopp, Sr.

## New Business

**Discussion of the IAS Section Structure.**—Don Ruch raised the question if the current section structure adequately serves the Academy. A copy of an e-mail to all Section Chairs was passed out, as a summary of abstracts, attendance and membership over the period 1985–2002. A general discussion followed. The Section Chairs are to bring up this question of the adequacy of the section structure at the respective Section Meetings in connection with the Fall 2004 Meeting of the Academy and report back to the President at that time.

**Evaluation of Student Presentations.**—Don Ruch presented for approval "Implementation of Scientific Presentation Rubric for Evaluation of Student Presentations at the Annual Meeting." Uwe Hansen moved approval, Damian Schmelz seconded. Passed unanimously.

**Discussion of Corporate Membership &**

**Advertising Committee.**—This agenda item was deferred until a later date.

**Budget Committee Actions.**—Minutes of the 13 December 2003 Budget Committee were passed out. The Budget Committee proposed the following dues increases:

Member ($5 — raised to $35)
Sustaining ($10 — raised to $60)
Associate ($5 — raised to $30)
Corporate ($250 — raised to $500)
Institution ($100 — raised to $200)
Student member (no change — still $10)
Emeritus member (no change — still $10)
Club member (no change — still $10)
Life member (no change — still $500)

This was passed unanimously by the Council and was referred to the 2004 Fall Meeting for a final vote by the General Membership.

Information item from the Budget Committee: The Local Arrangements Committee may set the registration fee for the meeting based on local cost level to between $20–$35. This year (2004) the fee will be $25.

**Technical Council.**—Uwe Hansen introduced a written proposal. Don Ruch suggested to Dr. Hansen that he discuss this with the individual Section Chairs and try it out for the Fall 2004 meeting. At this time no budget was attached to this agenda item.

**Other Business.**—Jim Berry, for the Publications Committee, moved to rescind page charges starting 2004. Passed unanimously.

Nelson Shaffer announced that the IAS current contact list is available from his office.

The meeting adjourned 5:42 PM.

Respectfully submitted,
Nils I. Johansen, P.E.
Secretary

## COMBINED MEETING OF THE EXECUTIVE COMMITTEE AND THE COUNCIL

Hanover College
28 October 2004

President Don Ruch called the meeting to order at 2:05 PM. Attending: President Don Ruch, President-Elect Uwe Hansen, Past-President Bob Waltz, Treasurer Edward Frazier, Secretary Nils I. Johansen, Executive Director Nelson Shaffer, Foundation Chair Frank A. Guthrie, Editor of the *Proceedings* Jim Berry, Research Grants/Local Host Committee Chair Jeff Hughes, Publications Chair Bill McKnight, Librarian Holly Oster, Historian William R. Gommel, Representative to the DNR Damian Schmelz, Representative to the AAAS Richard Kjonaas, Dick Conklin, Dan Webster, Stanley S. Shimer, Paul Rothrock, Mike Foos, Kimberly Lyle-Ippolito, Walter Hasenmueller, Randy Patrick, Clare Chatot, Evelyn Bowers, James Mitchell Smith, Terry West.

Minutes of the 16 April 2004 Spring Meeting of the Combined Executive Committee and Council at Hanover College were distributed and approved.

The name change, from "Combined Meetings of the Executive Committee and the Council" to "Council Meeting," was approved.

### Individual Reports

**Treasurer's report.**—Ed Frazier passed out financial reports and explained the various parts. Don Ruch indicated that he would suggest use of the Past-Presidents' Fund to support section activities. In an upcoming Newsletter he will discuss this further.

**Executive Director's report.**—Nelson Shaffer handed out a report on membership trends 1996–2004 for the various categories of membership. The total membership as of the meeting date stood at 809, down from 873 members in 2003, but at the same level as 2003 and 2002. He also discussed membership trends and reminded the attendees that he has a display that can be borrowed for use at meetings and also "have a friend join."

***Proceedings* Editor's report.**—Jim Berry said the current issue is at the press, and will come out in December. He also mentioned the current downward trend in submitted manuscripts (28 in 2002, 21 in 2003 and 14 in 2004) and encouraged the members to submit papers for inclusion in the *Proceedings*.

**Newsletter Editor's report.**—Uwe Hansen said Don Ruch will take over as Newsletter Editor next year (Hansen will be President of IAS). Hansen would like to see items in the Newsletter like "History" of something in Indiana and Indiana Science or "Biographies of Great Scientists" for inclusion.

**Secretary's report.**—Nils Johansen had earlier distributed minutes of the Spring meeting. The question was raised if the minutes should be on the website, but no action was taken on this.

**President-Elect's report.**—Uwe Hansen presented his agenda for his year as President. He would like to institute a "Technical Council." Seed money from this could come from the Past-Presidents' Fund. Hansen will meet with Section Chairs during lunch (29 October) and discuss this in more detail. He thought this would be a way to vitalize the sections, involve the Section Chairs, improve visibility in the State, and give the sections an opportunity to have special speakers at the annual section meeting. For example, the history of a discipline could also be written up and presented as a section paper at a future meeting of the section.

**President's report.**—Don Ruch made some comments on the search for a new Chair of the Youth Activity Committee and would come back to this later in the meeting.

### Committee Reports

**Foundation.**—Frank Guthrie distributed the Foundation financial report.

**Research Grants.**—Jeff Hughes distributed the report. For the Spring, 17 (out of 40) requests had been funded for a total of $33,415. Fall grants will be determined on 29 October (second round for this year). Junior Academy Grants will now be considered only once a year. The deadline is 1 November.

**Local Arrangements.**—Future meeting sites were discussed. The committee will meet 29 October. There are 180 attendees pre-registered for tomorrow's meeting. Future meetings sites are: Year 2005 at St. Mary-of-the-Woods College — Spring: 22–23 April; Fall: 6–7 October (note the early date). Year 2006 at Ball State University, with the Fall meeting during the first weekend in November. Year 2007 at University of Southern Indiana (tentative). Because of the early date for the Fall Meeting 2005, streamlining of the program booklet will be necessary. The abstract submission deadline will be as before (late August/early September). The program booklet will not be mailed out before the meeting, but it will be available at the meeting. After the meeting, the booklet will be mailed to members not attending. However, the program booklet will be available on-line before the meeting.

**Nominations and Elections.**—Mike Foos presented the election results, and they will also be announced at the General Business meeting on 29 October. Election results are: President-Elect: Clare Chatot; Academy Foundation: Wendell McBurney; Research Grants: Peter Scott. Nominations for next year will be requested in the Spring. Including the Section Chairs in the nomination and election process may increase the membership participation in the nominations and elections. In the election of the President, there has been an unofficial policy of alternating two "life science years" with one "physical science year." Bob Waltz was charged to look into this. As the current unwritten system operates, the candidates for President-Elect in 2007 (elected in 2006) will be from the physical sciences.

**Publications.**—Bill McKnight announced that *Periodical Cicadas* has been published and will be available for sale at the publications table during the meetings on the 29th. The Publications Committee will meet over lunch on 29 October.

**Finance.**—This item will be deferred until later in the meeting (Budget Committee).

**Resolutions.**—Nelson Shaffer submitted the resolution that will be read tomorrow thanking Hanover College for hosting the IAS meetings this year.

**Youth Activities.**—(including Junior Academy and Talent Search). Don Ruch summarized the efforts in obtaining a new Chair for this committee and announced that Patty Zeck has been apppointed the new Chair. Some discussion ensued regarding the system of rewards in the Junior Academy. The outcome was to let the committee decide.

**Library and Archivist.**—Holly Oster passed out a written report.

**Amendments.**—Bob Waltz reported no pending activity.

**Awards.**—Clare Chatot reported the following nominees: K. Michael Foos for Fellow, and Bob Waltz for Special Service Award. The nominees will be presented at the General Membership Meeting 29 October for approval by the membership. Chatot also encouraged the membership to nominate colleagues for Fellow if appropriate. The form is on the web-site.

**Biodiversity.**—Paul Rothrock reported on the plans for the upcoming Bio-Blitz, tentatively scheduled for sometime during the first two weeks in June 2007 at Fort Benjamin Harrison State Park in Indianapolis. The budget will be presented at the budget meeting this December. The effort should also be coordinated with the Publications Committee.

**Web Site coordinator.**—Nelson Shaffer read Marcia Moore's report.

**Speaker of the Year.**—Michael Foos will introduce Gene Kritsky at the annual meeting. Don Ruch stated that we all owe the committee our thanks.

**IAS Representative to INRC.**—Damian Schmelz handed out a written report.

**IAS Representative to AAAS.**—Richard Kjonaas reported. The next meeting of AAAS will be in Washington, DC. in February 2005.

**Historian.**—Bill Gommel reported the passing of the following members: William R. Adams, William B. Hopp, Sr. (1973 President of the Academy), Terry Kruger, Maud Ora Lang, Paul C. McKinney, Wilton N. Melhorn (1988 President of the Academy), and Howard R. Youse (1969 President of the Academy). The list will be read at the General Membership Meeting on 29 October, and they will be remembered with a moment of silence.

## Unfinished Business

**Corporate Membership and Advertising Committee.**—There was general discussion of the problem. The subject will be further discussed as an agenda item at the December 2004 Budget meeting.

**Budget Meeting.**—The Budget Meeting is tentatively set for 11 December at 10 AM in the Terre Haute area. Ed Frazier will need budget items by 1 December.

**Adjournment.**—Don Ruch thanked the Council and Executive Committee for their work on behalf of the Academy. The members responded by applauding Don for his work as President. The meeting adjourned at 5:18 PM.

Respectfully submitted.
Nils I. Johansen. P.E.
Secretary

## GENERAL BUSINESS MEETING
29 October 2004
Hanover College

**Speaker of the Year.**—Michael Foos introduced Dr. Gene Kritsky, Professor of Biology, College of Mount St. Joseph, and his talk on "Periodical Cicadas: The Plague and the Puzzle."

**Election Results.**—Michael Foos announced the results of the elections: President-Elect: Clare Chatot; Academy Foundation: Wendell McBurney; Research Grants: Peter Scott.

**Awards Committee.**—Clare Chatot read the names of the nominees. and the membership approved the following: Michael Foos for Fellow; Robert Waltz for Special Award.

**Historian.**—Bill Gommel read the list of departed members and the membership honored their memory with a moment of silence.

**Announcements.**—Don Ruch announced that the meetings next year will be at St. Mary-of-the-Woods College on 22–23 April and 6–7 October 2005. He reminded the members of the upcoming (2007) Bio-Blitz. He then gave a summary report of his term as President of the Academy. He thanked the Academy members for help he received that made last year a successful year for the Academy. As his last act, he passed the gavel to Uwe Hansen, the incoming President. The meeting was adjourned at 2:00 PM.

Respectfully submitted.
Nils I. Johansen, P.E.
Secretary

2005. Proceedings of the Indiana Academy of Science 114(1):82

# INDIANA ACADEMY OF SCIENCE
## 2004 Year End Financial Report

| | Balance<br>1-Jan-04 | Revenues | Expenses | Balance<br>31-Dec-04 |
|---|---|---|---|---|
| OPERATING FUND | | | | |
| Dues | | 21,090.00 | | |
| Interest | | 148.91 | | |
| Contributions | | 180.00 | | |
| Spring Meeting | | 400.00 | 557.83 | |
| Annual Meeting | | 7,320.00 | 7,481.39 | |
| Transfer from IAS Foundation | | 6,764.97 | | |
| Misc. Income | | 1,031.00 | | |
| Officer's Expenses | | | 4,021.99 | |
| Operating Expenses | | | 6,347.25 | |
| Financial Expenses | | | 1,302.90 | |
| Newsletter Expenses | | | 3,194.98 | |
| Library Operations | | | 0.00 | |
| Committee Expenses | | | 0.00 | |
| Speaker of the Year | | | 700.00 | |
| AAAS Representative | | | 875.00 | |
| Web Site Development | | | 2,000.00 | |
| Youth Activities | | | 11,647.50 | |
| Operating Fund Total | 9,055.02 | 36,934.88 | 38,128.84 | 7,861.06 |
| RESTRICTED FUNDS | | | | |
| Proceedings | 15,062.40 | 18,279.49 | 17,734.49 | 15,607.40 |
| Publications | 14,612.08 | 16,084.65 | 11,175.77 | 19,520.96 |
| * Research Grants | 16,027.02 | 59,845.11 | 59,845.00 | 16,027.13 |
| Indiana Biological Survey | (515.58) | 0.00 | 0.00 | (515.58) |
| Lilly Library | 6,578.44 | 0.00 | 0.00 | 6,578.44 |
| Welch Fund | 9,106.01 | 0.00 | 400.00 | 8,706.01 |
| Life Members Fund | 4,295.25 | 500.00 | 0.00 | 4,795.25 |
| Past Presidents Fund | 9,178.39 | 0.00 | 0.00 | 9,178.39 |
| Total Restricted Funds | 74,344.01 | 94,709.25 | 89,155.26 | 79,898.00 |
| Prepaid 2004 Dues | 4,170.00 | | | 4,375.00 |
| **TOTAL FUNDS** | **87,569.03** | **131,644.13** | **127,284.10** | **92,134.06** |
| FUNDS ON DEPOSIT | | | | |
| Checking Account | 8,692.52 | 121,216.42 | 128,159.95 | 1,748.99 |
| Money Market Savings | 67,820.13 | 69,708.56 | 58,200.00 | 79,328.69 |
| Cert. of Deposit | 11,056.38 | 0.00 | 0.00 | 11,056.38 |
| **TOTAL FUNDS DEPOSITED** | **87,569.03** | **190,924.98** | **186,359.95** | **92,134.06** |

* Provided 29 senior member grants and 17 high school grants.

| | Balance<br>1-Jan-04 | Revenues | Expenses | Balance<br>31-Dec-04 |
|---|---|---|---|---|
| ACADEMY FOUNDATION FUNDS | | | | |
| John S. Wright Fund Account | 6,366,524.00 | | | 6,443,101.13 |
| Academy Fund Account | 234,527.00 | | | 242,405.60 |
| Invested Income Account | 316,093.00 | | | 384,885.45 |
| **TOTAL FOUNDATION FUNDS** | **6,917,144.00** | | | **7,070,392.18** |

| **Foundation Funded Used For:** | |
|---|---|
| General Fund | 6,764.97 |
| Proceedings | 8,923.49 |
| Publications | 6,656.33 |
| Research Grants | 53,395.00 |
| **Total** | **75,739.79** |

Edward L. Frazier
Treasurer

# INSTRUCTIONS TO AUTHORS

*(revised July 2005)*

**General information.**—Manuscripts and all correspondence should be sent to the Editor. To be eligible for publication in the *Proceedings*, at least one author must be a member of the Academy. Papers that have been presented at an Academy meeting may be given preference for publication. Submission of a manuscript to the Editor implies that it has not been sent to another publication, nor has it been published elsewhere. If it is accepted for publication in the *Proceedings*, it may not be republished without the written consent of the Academy.

All manuscripts are evaluated by referees. Submit three copies of the manuscript. Figures in manuscripts for review may be submitted as photocopies, and they should be approximately the size that they will be printed in the *Proceedings*.

After the manuscript has been accepted, the author will be asked to submit the manuscript as a paper copy and on a computer disc in a widely-used word processing program. Indicate clearly on the computer disc the **word processing program** and the **type of computer** (Mac or PC).

Galley proofs will be sent to the primary author for approval and correction.

**Voucher specimens and permits:** Voucher specimens of species used in scientific research should be deposited in a recognized scientific institution. Authors must indicate that the collection of specimens, especially of threatened or endangered species, was authorized by the appropriate governmental organizations. All type specimens must be deposited in a recognized museum collection.

**Style.**—Do not use right or full justification. Also, use a non-proportional font (e.g, Courier, but not Times Roman).

**Title page.**—The title page should include (1) the title in capital letters, (2) each author's name and address, (3) the running head (see below), and (4) the complete name, address, and telephone number of the author with whom proofs and correspondence should be exchanged, a FAX number and electronic mail address if available.

**Abstract.**—All manuscripts have an abstract, which should summarize the significant facts in the manuscript. The "ABSTRACT" heading in capital letters should be placed at the beginning of the first paragraph set off by a period. Use complete sentences, and limit the abstract to one paragraph and 250 words.

**Keywords.**—Give 3–5 appropriate keywords following the abstract.

**Text.**—Double-space text, tables, legends, etc. throughout. Three categories of headings are used. The first category (METHODS, RESULTS, etc.) is typed in capitals, centered, and on a separate line. The second (lower) category of heading, in bold type, begins a paragraph with an indent and is separated from the text by a period and a dash.(This paragraph begins with an example of this heading.) The third heading category may or may not begin a paragraph, is italicized and followed by a colon. (The paragraph below is an example.) Use only the metric system unless quoting text or referencing collection data.

*Citation of references in the text:* Cite only papers already published or in press. Include within parentheses the surname of the author followed by the date of publication. A comma separates multiple citations by the same author(s) and a semicolon separates citations by different authors, e.g., (Smith 1990), (Jones 1988; Smith 1993), (Smith 1986, 1987; Smith & Jones 1989; Jones et al. 1990).

**Literature cited section.**—Use the following style, and include the full unabbreviated journal title. Repeat the name for multiple references by the same author. Note that book titles have the first letter of each word capitalized.

Walter, J. & B. Hallet. 1979. Geometry of former subglacial water channels and cavities. Journal of Glaciology 23:335–346.

Walter, J. 1992. The significance and complexity of communication in moths. Pp. 25–66, *In* Insect Communications: Mechanisms and Ecological Significance. (P.N. Work & J.S. Rivers, eds.). Princeton University Press, Princeton, New Jersey.

**Footnotes.**—Footnotes are permitted only on the first printed page to indicate current address or other information concerning the author. These are placed together on a separate page at the end of the manuscript. Tables and figures may not have footnotes.

**Running head.**—The author's surname(s) and an abbreviated title should be typed all in capital letters and must not exceed 60 characters and spaces. The running head should be placed near the top of the title page.

**Tables.**—These should be typed double-spaced, one table to a page and numbered consecutively. Most tables contain only three horizontal lines (see recent issues for examples). Do not use vertical lines or shading. Include all pertinent information in the table legend (no footnotes).

**Illustrations.**—All art work must be camera-ready (mounted and labeled) for reproduction. Figures should be arranged so that they fit (vertically and horizontally) the printed journal page, either one column or two columns, with a minimum of wasted space. When reductions are to be made by the printer, pay particular attention to width of lines and size of lettering in line drawings. Multiple photos assembled into a single plate should be mounted with only a minimum of space separating them. In the case of multiple illustrations mounted together, each illustration must be numbered Fig. 1, Fig. 2, etc.) rather than given letter (A,B, etc.) designations. The name(s) of author(s), and an indication of top edge, and whether the illustration should be one or two columns wide, should be written on the back of the illustration. The overall dimensions should be no more than 11 inches (28 cm) × 14 inches (36 cm). Larger drawings present greater difficulty in shipping and greater risk of damage for which the *Proceedings* assumes no responsibility. In manuscripts for review, photocopies are acceptable, and should be reduced to the exact measurements that the author prefers in the final publication. Make notations in the text margins to indicate the preferred position of illustrations in the printed text. Color plates can be printed; but the author must assume the full cost, currently about $600 per color plate.

Legends for illustrations should be placed together on the same page(s) and separate from the illustrations. Each plate must have only one legend, as indicated below:

Figures 1–4.—Right chelicerae of species of *Centruroides* from Timbuktu. 1. Dorsal view; 2. Prolateral view of moveable finger; 3. *Centruroides* holotype male; 4. *Centruroides* male. Scale = 1.0 mm.

**Page charges and reprints.**—There are no page charges for members of the Academy. Corrections in proof pages must be restricted to printer's errors only; all other alterations will be charged to the author (currently $3 per line).

Reprints are available only from the Allen Press and should be ordered (with payment) when the author receives the proof pages. Allen Press will not accept reprint orders after the paper is published.

## CONTENTS

# *Proceedings* of the Indiana Academy of Science

**Volume 114 Number 1 2005**

*Geology*

**Barometric and Earth-tide Induced Water-level Changes in the Inglefield Sandstone in Southwestern Indiana** by Paul C. Inkenbrandt, Paul K. Doss, Thomas J. Pickett, and Robert J. Brown .... 1

*Botany*

**An Evaluation of Indiana's Floristic Quality Assessment** by Paul E. Rothrock and Michael A. Homoya .... 9

**Distribution Records of Southern Indiana Vascular Plants II** by William E. Thomas, Scott P. Ash, and Richard H. Maxwell .... 19

**A Vascular Plant Inventory of Howell Wetlands, A Nature Preserve Within the City of Evansville, Indiana** by Jennifer Keller, Edith Hardcastle, and Scott A. Gordon .... 26

*Zoology*

**Freshwater Mussel (Bivalvia: Unionidae) Survey of the Brouilletts Creek Basin in Illinois and Indiana** by Jeremy S. Tiemann .... 33

***Orconectes* (*Procericambarus*) *theaphionensis* (Decapoda: Cambaridae), the Sinkhole Crayfish, a New Species of Crayfish from Southcentral Indiana** by Thomas P. Simon, Anne E. Timm, and Charles C. Morris .... 43

**Notes on Indiana Crayfish (Decapoda: Cambaridae) with Comments on Distribution, Taxonomy, Life history, and Habitat** by Thomas P. Simon, Matthew Weisheit, Elizabeth Seabrook, Lori Freeman, Scott Johnson, Lynn Englum, Katherine W. Jorck, Matthew Abernathy, and Thomas P. Simon IV .... 55

**Discovery of an Exotic Asian Mosquito, *Ochlerotatus japonicus*, (Diptera, Culicidae) in Southern Indiana** by Steven P. Moberly, Craig Lalor, Mollie McDonough, Brad Foster, Adam Estes, and Douglas J. Bentfield .... 62

**Observations of Periodical Cicadas (Brood X) in Indiana and Ohio in 2004 (Hemiptera: Cicadidae: *Magicicada* spp.)** by Gene Kritsky, Jennifer Webb, Michael Folsom, and Margie Pfiester .... 65

**Nocturnal Behavior and Roosting Ecology of a Juvenile *Lasiurus cinereus* Near Indianapolis, Indiana** by Dale W. Sparks, Christopher M. Ritzi, and Brianne L. Everson .... 70

**Bat Communities in Highly Impacted Areas: Comparing Camp Atterbury to the Indianapolis Airport** by Wade A. Ulrey, Dale W. Sparks, and Christopher M. Ritzi .... 73

*Indiana Academy of Science*

**Minutes of Meetings for 2004** .... 77

**Financial Statement for 2004** .... 82